COMPUTER SIMULATION OF THE COOPERATIVE APPROACH TO TRACTOR MECHANIZATION IN A DEVELOPING COUNTRY

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This is to certify that the

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ABSTRACT

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The experience of the Bangladesh Academy for Rural Development and the Kotwali Thana Central Cooperative Association in introducing agricultural development into the Comilla Thana (County) of Bangladesh was used as the basis for developing the computer simulation model and for determining the ability of small farmers to participate in agricultural development efforts.

Various arrangements for owning and utilizing tractor mechanization in developing countries were discussed. These included private ownership, group ownership by neighboring farmers, individual ownership with

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custom hire services provided other farmers, government operated tractor hire services, and cooperative tractor hire services.

The computer simulation model was divided into a generalized model for tractor hire service operation, a model for simulating demand for tillage by farmers in village level cooperatives, and a model for simulating tractor breakdowns and repairs.

The generalized model was capable of simulating the daily operation of a cooperative, government, or individual owner contract hire tractor service. Demand in the model was in the form of either wet land or dry land tillage. Tillage work in the tractor hire service model was performed in the order in which requests were received. The model provided for the assignment of equipment to tractors and the assignment of tractors to demand. The model also provided for the withdrawal of demand when delays occurred in performing demand.

The demand model for tillage by farmers in village level cooperatives was based upon the use of irrigation, the use of improved crop varieties, the average acreage grown per farmer, the number of persons in a cooperative, and other characteristics of farmers and cooperatives.

The repair model was used to predict the occurrence of a breakdown of individual tractors, to predict the duration of the repair once a breakdown occurred, and to predict the cost of repairing the breakdown. The occurrence, duration, and cost were all considered to be random in nature but related to tractor use.

LeVern William Faidley

Conclusions from the study include the following:

1. Small farmers in developing countries can participate in agricultural development programs and successfully use appropriate forms of mechanization.
2. Mechanized irrigation, the introduction of improved crop varieties, and the selective mechanization of certain crop production operations were found to be appropriate forms of agricultural development for many developing countries.
3. Small farmers were found to require specialized organizations such as cooperatives to effectively participate in agricultural development programs.
4. Some type of tractor hire service as opposed to private ownership appears to be the most appropriate method of introducing agricultural mechanization in labor surplus developing countries.
5. Over a narrow range, small decreases in the number of tractors in a tractor hire service results in large increases in the percent of farmers who have their demand delayed.
6. The large increases in international prices of petroleum and farm machinery can be expected to increase the cost of tractor hire services by 50 to 70%.

Approved: ______________ Major Professor

Approved: ______________ Department Chairman

COMPUTER SIMULATION OF THE COOPERATIVE APPROACH TO TRACTOR MECHANIZATION IN A DEVELOPING COUNTRY

By

LeVern William Faidley

A DISSERTATION

Submitted to
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This work is dedicated to my wife

Barbara

for her love, encouragement,

assistance, and sacrifice

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CHAPTER 1

1.0 INTRODUCTION

The developing countries of the world are confronted with the problem of introducing agricultural development methods which are compatible with their labor employment needs and their requirements for adequate food production. Agricultural mechanization, defined to include production aids ranging from improved hand tools up through mechanical power units with associated equipment, can play an integral part in many of these development programs. The question, however, arises as to whom in the rural sector development efforts should be directed and what form, if any, mechanization should take in these programs. One hypothesis which is gaining support is that no segment of the rural population should be excluded from development programs. It is possible and desirable to design agricultural development programs which provide an equitable distribution of benefits regardless of farm size. Labor generative mechanization can be an important aspect of these programs

For the desirability of including the smallest farmers and even the rural landless labor in agricultural development programs one need only look at the increasing populations in the developing countries of the world. Annual growth rates during the 1960s were estimated to be 2.8% in South Asia, 2.7% in Africa, and 3.7% in South America.(United Nations, 1966). The industrial and service sectors of many developing countries, although growing, are not generating employment as fast as the population is increasing. Abercrombie writes, "When most of the population is still in the rural areas and the agricultural labor force is still growing in absolute numbers as in most of the developing countries, the agricultural and rural sectors are likely to have to bear much of the burden of employment." (Abercrombie, 1972) Since unoccupied arable land is scarce in many countries especially in developing countries, the size of land holdings per family can be expected to decrease. In order to increase or even maintain the standard of living on these already small and decreasing land holdings and thus encourage these persons to remain in the rural area, it is highly desirable that they be included in agricultural development programs.

Many development planners, economists, and engineers have proposed that development programs, and thus mechanization, be directed mainly toward larger farmers. The idea is to establish larger commercial type farms to produce a marketable surplus sufficient to meet the production needs of the country while eliminating the small subsistence farmer or leaving him to eke out a substandard living using traditional methods. For example, the economist S.S. Johl has written, "To the extent total production and marketable surplus per unit of land increases, the increase in the farm size should be acceptable, or reduction in farm size leading to decreased productivity should not be acceptable, even if it (larger farms) may mean marginally lower employment." (Johl, 1973) As another example, the agricultural engineer Giles has written concerning agricultural mechanization in West Pakistan, "As a generalization, the 0 to 25 acre farms can be classed for animal powered farming and the 25 acre and above farms for tractor power." (Giles, 1967) Stout has also written, "There is no doubt that draught animals will be an important source of power on small farms for many years to come. However, for commercial farming draught animals are an interim primary source of power and supplementary source of power during a transitional phase." (Stout and Downing, 1973)

Statements such as these do not meet the needs and aspirations of the small subsistence farmers. If it could be proven that small subsistence farmers could not participate in or directly benefit from agricultural development and mechanization programs, excluding them might be justified. However, evidence on some of the smallest farms in the world indicates that small farmers can participate in development programs and use appropriate forms of mechanization as successfully as larger farmers. This chapter discusses multiple cropping as a method of agricultural development, defines some of the selective mechanization requirements of small farmers, and presents evidence to justify inclusion of small farmers in development efforts.

1.1 MULTIPLE CROPPING AND THE SMALL FARMERS

With unoccupied arable land now nearly exhausted, the critical problem facing many Asian countries is how to intensify cultivation and increase the standard of living on already small and decreasing land holdings. Multiple cropping has the potential of helping accomplish this task.

Taiwan has illustrated the benefits of multiple cropping. Between 1915 and 1965 the multiple cropping ratio (i.e. the ratio of the total area planted each year to the area of cultivated land) in Taiwan rose from 1.32 to 1.98. During this 50 year period, the number of agricultural workers increased by 50% and the number of days worked by each person increased by about one third. The agricultural output per worker also rose by 250% during this period (Shaw, 1970). This means that the productivity and income per agricultural worker increased considerably.

To accomplish this in Taiwan, the multiple cropping ratio increased an average of 3.3% per year between 1945 and 1960 (Lee, 1971). Many Asian countries are presently at a critical point of over population, under production, and under employment; and they must strive to attain a similar growth rate in the multiple cropping ratio.

The most effective methods of increasing the multiple cropping ratio thus far identified are 1) irrigation, 2) the introduction of improved varieties of crops, and 3) management of cultural practices using selective mechanization.

The experience in the Comilla Thana (County) of Bangladesh illustrates the application of the above methods.

1.2 BANGLADESH: A MODEL FOR SMALL FARM DEVELOPMENT

The Comilla Thana, Bangladesh has been used as a rural development laboratory by the Bangladesh Academy for Rural Development since 1960. For a discussion of the Comilla Academy refer to Appendix A. The experiences in Comilla demonstrate that small farmers can participate in and benefit from rural development programs. Farms in Comilla are some of the smallest in the world, and the farmers some of the poorest.

Farm Size and Subsistence Incomes in Comilla Thana

The Comilla Thana in 1969 contained 51,560 acres (20,900 ha) of agricultural land and had a population of approximately 200,000 people, with an average density of 2500 people per square mile. In 1969 there were approximately 31,000 families living in census villages in the Thana. About 15% of the families were landless and about 70% owned less than 2 acres (.8 ha) as shown in Table 1.1 (Muyeed, 1969).

Table 1.1 Land Holdings of Agricultural Families

Land Holdings		Percent of Families
Acres	Hectares	
nil	nil	15
0.01 - 0.8	0.01 - .32	26
0.81 - 2.0	0.33 - .80	28
2.01 - 4.0	0.81 - 1.60	18
4.01 - 6.0	1.61 - 2.40	8
over 6.0	over 2.40	5

The mean land holding per rural family was 1.46 acres (.59 ha). In almost all cases land holdings consisted of fragmented, widely scattered plots, ranging in size from 0.10 acres (.04 ha) to 0.40 acres (.16 ha) with a negligible number of plots larger than 1 acre (.4 ha).

Table 1.2 (Muyeed, 1969) presents data on income levels of the families living in the agricultural villages, as appraised by the families themselves.

Table 1.2 Income Levels of Agricultural Families

Income Levels	Percent of Families
Income below subsistence level	44
Income at subsistence level	27
Income above subsistence level	22
Income at higher level	7

This table shows that 44% of the families considered themselves as living at less than a subsistence level of income, while 27% considered themselves at a subsistence level. Table 1.1 indicated that 41% of the people had less than 0.80 acres (.32 ha) or were landless, while 28% of the people had from 0.8 to 2.0 acres (.32 to .8 ha). Thus, if it is assumed that there is a correspondence between land holding size and income levels, then the landless and those families with less than 0.80 acres (.32 ha) (41%) probably had incomes below the subsistence level, while those with 0.81 to 2.0 acres (.32 to .80 ha) (28%) would appear to have had incomes approximately at the subsistence level. Families with more than 2.0 acres (.80 ha) would then make up the majority of persons with incomes above the subsistence level.

The Cooperative Approach in Bangladesh

Participation of farmers, such as those mentioned above, in development programs required specialized organizations, since farmers at or below a subsistence level of income could not individually afford the investment requirements of improved farming methods. In Comilla, this organization took the form of a two stage cooperative. Primary cooperative societies were organized in the agricultural villages and a central cooperative called the Kotwali Thana Central Cooperative Association (KTCCA) was established at the thana level. The function of the central cooperative was to provide the primary cooperatives with 1) banking and supervised credit, 2) agricultural extension and training, 3) agricultural inputs, including fertilizer, insecticides, and machines, 4) water development, irrigation, and rural electrification, and 5) processing and marketing facilities. The primary village cooperatives encouraged their members to use improved farming methods, distributed the production loans and crop inputs available from the central cooperative, and supervised the collection of savings, share purchases, and the repayment of loans from their members.

Membership in Comilla Cooperatives

The Academy for Rural Development introduced the cooperative scheme into Comilla Thana in 1960. Rapid growth took place in the primary cooperative societies following their introduction and resulted in a membership in which members owned 51% of all land in the thana in 1969 which is shown in Table 1.3 (PARD Annual Report, 1967, 1969). Over 37% of the families in the thana belonged to cooperatives in 1969.

Table 1.3 Growth of Cooperative Membership and Land Ownership in the Comilla Thana

Item	64-65	65-66	66-67	67-68	68-69
No. of agricultural coops	152	158	225	251	301
No. of Coop members	4910	5161	8462	11,518	11,673
Families who are coop members, %	15.7	16.5	27	36.7	37.3
Land owned by coop members, acres	10,100	11,700	19,150	26,050	26,410
hectares	4100	4740	7750	10,550	11,100
Total land owned by coop members, %	19.6	22.7	37.2	50.5	51.2

The largest single category of cooperative members (43%) were farmers with land holdings from 1 to 2 acres (.4 to .8 ha) as shown in Table 1.4 (Akhter, 1964; PARD Annual Report, 1969). Of farmers with this size land holding, 68% belonged to cooperatives. Most cooperative members possessed medium and larger land holdings. Families with more than one acre (.4 ha) made up 86% of the cooperative membership while only 55% of the total population owned one acre (.4 ha) or more. The landless and near landless, those with less than one acre (.4 ha), make up over 45% of the total population, however, they represented only 14% of cooperative membership.

There are several reasons which may explain why the landless and near landless families did not belong to the cooperatives. First, Comilla

Table 1.4 Distribution of Total Population and Cooperative Membership by Farm Size

Farm Size in acres	Farm Size in hectares	% of total rural population with given farm size	% of cooperative members with given farm size	% of rural population with given farm size who are coop members
nil	nil	15.3	2	5
.01-1.0	.01- .4	30.5	12	15
1.01-2.0	.41- .8	24.2	43	68
2.01-3.0	.81-1.2	14.4	18	47
3.01-5.0	1.21-2.0	10.6	16	56
over 5.0	over 2.0	5.0	8	60

cooperative societies required that members make regualr cash and in kind savings deposits, which many families with low incomes would find difficult to do. Second, the loan policy of the cooperative generally excluded persons with less than one acre (.4 ha) from taking its loans, and thus, the small landholders and low income families could not easily benefit from cooperative membership. Fortunately, this did not prevent some of these persons from benefiting from the agricultural transformation which has taken place in Comilla Thana.

1.3 CROPPING SEASONS

Bangladesh has tropical temperatures and a summer monsoon climate with rainfall averaging a total of 94 inches (238 cm) per year. The summer months of June through September all have more than 10 inches (25.4 cm) of rainfall each month. The heavy rainfall during these months causes flooding of the great alluvial plains of the Ganges and Barhmaputra River systems. The winter months from November through March are the dry season and have less than 1/4 inch(.63 cm) of rainfall per month. Because of the climatic pattern,Bangladesh including the Comilla Thana has three possible cropping seasons. The two traditional cropping seasons were during the early and latter parts of the monsoon period. The early monsoon season is referred to as the Aus season and the latter monsoon season as the Amon season. Water was available but in uncontrollable quantities during both of these seasons so excessive flooding and crop losses often resulted. The winter dry season (Boro season) provides a possible third cropping season if water can be procured.

1.4 IRRIGATION - A STRATEGY FOR AGRICULTURAL DEVELOPMENT

Mechanized irrigation with low-lift power pumps was started in the Comilla Thana in the winter of 1960. The power pump provided a stimulation to production and income because an extra rice crop resulted. There were, however, major limitations both in organization and water resources. The chief limitation in resources was the lack of readily available water for low-lift pumping. The Gumti River flows through one corner of the thana but the only other water available was from small streams and ponds. Many of these sources dried up toward the end of the dry winter season in several villages, thus, adversely affecting the crop yield.

Organization of land for water distribution presented another major difficulty. Because of the small fields and scattered land holdings, the technically simple task of building a small water canal across a quarter mile of level alluvial plain became a major organization problem. Even a wealthy man could not afford to purchase the easements and rights-of-way needed to irrigate all of his plots. Therefore, the only solution was for all of the owners to come together and agree that canals could be built across their lands. This was best accomplished through the village cooperative societies.

A third problem with the low-lift pump program was that of pump operators. They,being from outside the thana,did not want to live in the villages, nor did the villagers want them. Some operators would deliberately break the pumps so they could go on leave. This problem was overcome by the Academy when they began training village boys as pump operators. Selected village boys were taught the rudiments of mechanics and machine care. After about three weeks of training they were sent back to their villages to operate their own pump. Immediately after the installation of these resident operators, the hours of pump operation increased and breakdown time decreased.

A final problem was the servicing and maintenance of the pumps. It was determined that this could be best done by a centrally located servicing section and with roving mechanics that visited the villages.

Thus, in the first year of winter irrigation, the following conclusions were made: (Rural Coop. Pilot Experiment, 6th Annual Report, 1966).

1. The effective use of pumps would require cooperative society organizations in the villages.

2. The Central Association would need to own, maintain, and repair the pumps and then rent them to the village cooperative societies.

3. The pump operators and mechanics should be persons from the villages who were trained by the Academy.

4. To prevent shortages of irrigation water, research should be conducted to find additional water sources.

5. The production of an additional crop by irrigation was a positive contribution to agricultural productivity and farmer income.

In 1962, after three years of experience, it was concluded there was not sufficient surface water in the Comilla Thana to support widespread irrigation. The decision was then made that tube-wells should be installed to supplement the surface sources of water. Fortunately, an abundant supply of fresh water is available below the ground surface in the Comilla Thana, as well as many other areas of Bangladesh.

The first experimental 6" diameter tube-wells were installed in 1963. The experience gained from this experimental work led to the development of "The Comilla Pilot Project in Irrigation and Rural Electrification". This project began in 1964 as a joint venture between the KTCCA, and the East Pakistan Water and Power Development Authority(EPWAPDA). The purpose was to develop a comprehensive irrigation system to meet the needs of the entire Comilla Thana.

The project consisted of three different methods of water supply:

1. A gravity-flow system from the Gumti River into large distribution channels from which water could be pumped with low-lift pumps to irrigate land near the channels.

2. Irrigation by low-lift pumps floated on rafts in the Gumti River, which could be used to irrigate land near the river.

3. Deep tube-wells located in places where irrigation by either of the other two methods was impossible.

Trends in Winter Irrigation

The experience gained during the first five years led to rapid expansion of mechanized irrigation, as shown in Table 1.5. (Winter Crop Cutting Survey, Comilla Kotwali Thana, 1965-1969) Natural irrigation in Table 1.5 refers to areas where sufficient water to grow a crop was available without either manual or mechanized irrigation.

Table 1.5 Winter Crop Coverage Under Different Irrigation Methods

Irrigation Method	1964	1965	1966	1967	1968	1969
Tube-well, acres	423	1018	1127	2412	3891	6203
hectares	171	412	456	976	1575	2510
Power Pump, acres	500	129	178	727	1227	2324
hectares	202	52	72	294	497	941
Total Mechanized, acres	923	1147	1305	3139	5118	8527
hectares	373	464	528	1270	2072	3451
Manual, acres	NA*	6024**	5493	3967	2186	1430
hectares	NA*	2438**	2223	1605	885	579
Natural, acres	NA*	1290**	870	874	1324	853
hectares	NA*	522**	352	354	536	345
Total Traditional, acres		7314	6363	4841	3510	2283
hectares		2960	2575	1959	1421	924
Total, acres		8461	7668	7980	8628	10,810
hectares		3424	3103	3229	3493	4375

* Not Available
** Analysis of the methods used to estimate these acreages indicates they are probably higher than the actual acreage

The acreage under natural irrigation was about 850 acres (340 ha) annually. This increased in years when there was unusually large amounts of rain during the last half of the Amon season as in 1965 and 1968.

Mechanized irrigation increased substantially each year, shown in Table 1.5. Manual irrigation (manpower used to lift water with various divices), however, decreased during the same period. Although manual irrigation methods have been knows for centuries, before 1962 there was a total of less than 1500 acres (600 ha) irrigated in the whole Comilla Thana. Even water available near fields was not used effectively to grow crops. However, once power pumps demonstrated the advantages of winter irrigation, people started adopting other forms of irrigation. The number of tube-wells and power pumps was limited in the early years. Thus, more people were stimulated to use manual irrigation. As the availability of mechanized irrigation increased, it replaced most of the manual irrigation.

The introduction of mechanized irrigation has brought about extensive changes in the winter cropping patterns of the Comilla Thana. Acreages of different winter crops grown in the thana are given in Table 1.6 (Winter Crop Cutting Survey, 1965-1969). The acreage devoted to local rice varieties has decreased every year since 1965. During 1965, 1966, and 1967 this decrease was mainly due to a switch from rice to non-rice crops. The non-rice crops were grown because they required from 100 to 150% less water than rice. Thus, a person could more easily move enough water manually to grow a non-rice crop. Also, financial returns for crops such as potatoes and watermelons were from three to eight times greater than returns from local varieties of rice. Acreage of non-rice crops reached a peak in 1967 and has decreased steadily since then. Several factors have combined to cause this decrease. The two most important are 1) the introduction

Table 1.6 Acreage for Different Winter Crops in Comilla Kotwali Thana

	1965	1966	1967	1968	1969
Improved paddy, acres	----	185	631	4420	7390
hectares	----	75	255	1789	2991
Local paddy, acres	6296	4840	3855	1959	1538
hectares	2548	1959	1560	793	622
Total rice, acres	6296	5025	4486	6379	8928
hectares	2548	2034	1815	2582	3613
Potato, acres	322	1048	539	443	511
hectares	130	425	218	179	207
Watermelon, acres	---	210	251	79	64
hectares	---	85	102	32	26
Vegetables, acres	516	258	256	341	373
hectares	209	104	104	138	151
Sweet Potato, acres	268	445	732	789	596
hectares	108	180	296	319	241
Others, acres	1057	682	989	597	338
hectares	428	276	400	242	137
Total Non-Rice, acres	2163	2643	2767	2249	1882
hectares	875	1070	1120	910	762
Total Area, acres	8456	7668	7253	8628	10,810
hectares	3423	3104	2935	3492	4375

of high yielding rice varieties, such as IRRI-8, made improved varieties of rice the most profitable crop to grow and 2) the large increase in the number of tube-wells and low-lift pumps during these years made water available in sufficient quantities to grow rice.

Central Organization for Irrigation

To provide the services needed by the thana-wide irrigation program a water development section was established as a part of the Central Machine Station of the KTCCA. This section was made responsible for sinking tube-wells and training well-drilling crews.

The village cooperatives obtained use of irrigation facilities by filing a request with KTCCA. The KTCCA then notified the Machine Station which would install either a surface water pump or a tube-well for the village cooperative society. The Machine Station received yearly rental fees from the village societies for the tube-well or pump. The total rental fee was collected from the village societies before the start of the irrigation season. A portion of the rental fee was, however, subsidized by the government. In 1969, the Machine Station received $245.00 (Rs. 1200.00) annual rental for each tube-well or pump. The Machine Station was then responsible for the salary of the operator, and all costs of repair, overhaul, spare parts, etc. required for the pump operation.

The farmer's costs included pump rental, purchase and transportation of fuel and oil, excavation and maintenance of field channels, and other miscellaneous expenses. In 1969, this cost amounted to about $17.00 per acre ($6.90/ha), i.e. Rs. 81.00/acre. (Mohsen, 1969)

The acreage covered per tube-well and surface water pump is shown in Table 1.7 (Mohsen, 1969). This table shows that the number of tube-wells and surface pumps increased substantially each year since 1966. The acreage covered per irrigation unit, however, has been decreaseing for

Table 1.7 Coverage Per Irrigation Unit in Comilla Thana

	1964-65	1965-66	1966-67	1967-68	1968-69
Number of Pumps	3	4	17	37	67
Acres irrigated/pump	42.93	44.57	42.73	34.92	34.67
Hectares irrigated/pump	17.37	18.04	17.29	14.13	14.03
Number of Tube-wells	34	25	36	91	126
Acres irrigated/tube-well	29.59	45.09	51.09	42.76	49.23
Hectares irrigated/tube-well	11.98	18.25	20.68	17.30	19.92

the surface water pumps for the last four years. The coverage by tube-wells was consistently larger than that of the surface water pumps each year with a maximum irrigation coverage of about 50 acres (20 ha) per well. Most of the tube-wells and surface pumps had rated output capacities of 2 cubic feet per second (cusec)(57 liter/sec). Therefore, in 1969, the coverage was 17.35 acres/cusec (.25 ha/liter/sec) for the surface pumps and 24.62 acres/cusec (.35 ha/liter/sec) for the tube-wells. The average coverage for all pumps in other irrigation projects in Bangladesh was 20.71 acres /cusec (.30 ha/liter/sec) in 1969. Thus, the Comilla Thana coverage per surface pumps was below the national average while the coverage per tube-well was above. One reason for better coverage by tube-wells over surface pumps was their centralized location in the area to be irrigated. The surface pumps had to be located at the water course, thus, distribution distances were greater and more difficult and losses more excessive than for the tube-wells.

Although the pumps were rented to the village cooperative societies, use of the water was not limited to cooperative members. Often persons who were not members of the cooperative, but who had land within the area which could be irrigated, purchased irrigation water from the cooperative societies, usually at a price for the water somewhat higher than that paid by cooperative members. This has permitted persons who were not cooperative members to participate in winter cropping and derive benefits from it.

Benefits of Winter Irrigation

The benefits of irrigation for the small farmer can be illustrated by considering that under traditional farming conditions, assuming no costs of production other than what the family could provide, about 1 acre (.4 ha) of land was required to support a family of four at a subsistence level. With the introduction of irrigation and improved varieties of rice this same family of four could be supported on less than .85 acre (.35 ha) of land, even if costs of production were assumed to be 45% of the total value of the crop produced. The net return for irrigation amounted to as much as $250.00 per acre($618.00/ha) i.e. Rs.1200/acre for some of these farmers. This was a large income for those accustomed to living at a subsistence level. Also, the benefits extended beyond the grower of the crop. Irrigation allowed the growing of additional crops during this dry winter season when the land would otherwise have been fallow. Thus, winter cropping provided employment for a large agricultural labor force which might otherwise have been unemployed. Labor generation directly affecting the rural landless laborers increased dramatically as the result of mechanical irrigation. In 1965, 35,000 man-days of hired labor were used on 1147 mechanically irrigated acres (464 ha) during the winter season in Comilla Thana. In 1970, 450,000 man-days of hired labor were used on 8500 acres of mechanically irrigated land during this same season. This was a 13 fold increase in only 6 years. Benefits were further extended to the total population of the thana because the increased agricultural production made increased amounts of food stuffs available at lower prices.

1.5 THE IMPACT OF IMPROVED VARIETIES

As mentioned earlier the introduction of improved rice varieties provided the greatest impetus for increasing winter irrigation. By 1970, 98% of the winter irrigated acreage was planted to improved rice varieties in the Comilla Thana. Thus, an analysis of the use of improved rice varieties provides the best basis on which to evaluate the ability of small farmers to utilize irrigation. Since improved rice varieties have, at this writing, mainly been designed for use on irrigated land during the dry winter season, this discussion is limited to the introduction of improved varieties during this season. First, the effect of cooperative membership on the adoption and yield of improved varieties and the use of recommended practices will be discussed, followed by analysis of the effect of farm size on the growing of improved varieties.

Rate of Adoption

Improved rice varieties for the winter cropping season were first introduced for general use by farmers in the Comilla Thana in 1965. Cooperative members were the first to adopt improved varieties of rice and their rate of adoption was rapid, from 7% to 98% in only five years as shown in Table 1.8. (Winter Crop Cutting Surveys, 1966, 1967, 1969, 1970, raw data)

Table 1.8 Adoption of Improved Varieties

	1966	1967	1969	1970
Coop members	7%	31%	87%	98%
Non-members	--	1%	66%	98%

However, the rate of adoption by persons who were not cooperative members was even more remarkable, increasing from 1% to 98% in only four years. The lag in adoption by persons not in the cooperative can probably be attributed to the assumed high risk of growing improved varieties during their initial introduction. However, once it was demonstrated by about a third of the cooperative members that the varieties could be successfully grown, and that there were large economic benefits to be derived from them, adoption by almost everyone quickly followed. Until 1970 only three types of new varieties were grown: IRRI-8, Pajam, and Taipei-177. In 1970, however, the East Pakistan (Bangladesh) Rice Research Institute made available several additional improved varieties which were used by some of the cooperative members. The non-members, however, chose to grow only the three original improved varieties.

Yield

Yields from improved varieties were two to three times larger than for non-improved varieties each year. There was also a steady annual increase in yields for the improved varieties. The cooperative members were continually able to obtain higher yields for both improved and non-improved rice varieties. It is important to note, however, that although the yield for improved varieties was continually larger for cooperative members than non-members, the magnitude of the difference between their yields decreased from 24% in 1967 to 7% in 1970 as shown in Table 1.9. (Winter Crop Cutting Surveys, 1966, 1967, 1969, 1970, raw data)

Table 1.9 Yield for Improved and Non-Improved Rice

		1966	1967	1969	1970
Improved Rice:					
Coop members,	lb/acre	2896	3579	3622	3961
	md/acre**	35.09	43.49	44.02	48.14
	kg/ha	3244	4009	4057	4437
Non-members,	lb/acre	----	2732*	3321	3683
	md/acre	----	33.20*	40.36	44.76
	kg/ha	----	3060*	3720	4126
Non-Improved Rice:					
Coop members,	lb/acre	1394	1481	1584	1363*
	md/acre	16.94	18.00	19.25	16.56*
	kg/ha	1562	1659	1774	1526*
Non-members,	lb/acre	966	1252	1295	2070*
	md/acre	11.74	15.21	15.74	25.16*
	kg/ha	1082	1402	1451	2319*

* These values were derived from survey data containing less than four observations.

** 1 maund equals 82 pounds

In 1966 and 1967, with most persons growing non-improved rice varieties, cooperative members growing these varieties had 30% and 16% greater yields respectively than non-members. In 1970 with almost everyone growing improved varieties, cooperative members had only a 7% greater yield than non-members growing these varieties. Thus, it appears that the improved varieties contributed to an equalization of yields between cooperative members and non-members. The benefits of cooperative membership and its effect on yields therefore were actually less with the improved varieties than they were with the non-improved varieties.

Method of Sowing

The use of improved varieties have brought many changes in almost all farming operations. In 1966, 62% of the cooperative members and 40% of the non-cooperative rice growers broadcast their rice. Twenty-seven percent of the coop members and 58% of the non-members random transplanted their rice. Only 11% of the cooperative members and 1% of the non-members transplanted their rice in lines, even though this improved planting method was introduced as early as 1961. In 1970, 99% of both cooperative members and non-members used line transplanting. Line transplanting requires about 20 man-days per acre (50 man -days/ha) compared to 18 man-days per acre (45 man-days/ha) for random transplanting and 2 man-days per acre (5 man-days/ha) for broadcasting. Thus, the use of improved varieties significantly increased the labor requirement for sowing by accelerating the adoption of line sowing. Line transplanting is important in growing improved varieties since it makes cultivation and plant protection operations easier.

Weeding

Weeding is the second farming operation which has changed greatly with the introduction of improved varieties. In 1966, 60% of the cooperative members and 82% of the non-members did no weeding in growing the winter crop. In 1970 all of the cooperative members and all but 1% of the non-members used some type of weeding. Of those weeding in 1970, 70% of the cooperative members and 53% of the non-members used both hand and machine weeding while 29% of the cooperative members and 45% of the non-members used only hand weeding. Machine weeding refers to a small, one row weeder which is pushed by hand between the rows of rice in the paddy field. In hand weeding in 1966, both cooperative members and non-members weeded the crop an average of 1.25 times. In 1970 they weeded the crop an average of over 2.2 times. Those weeding with both machine and by hand, weeded over 3.7 times. This indicates a significant increase in the labor used to produce the improved varieties compared with the indigenous varieties.

Land Preparation and Threshing

The number of times a field is tilled before planting has also increased with the introduction of improved varieties, although this increase is not as significant as the increase in the number of weedings. In 1966 coop members tilled their fields with bullocks for the winter crop an average of 4.07 times while non-members tilled an average of 3.5 times. In 1970 both members and non-members tilled an average of slightly over 4.75 times. Since it requires a bullock pair about 2 days to till one acre (5 days to till one hectare) each time, the total time required for land preparation has increased from 8 to 9.5 days/acre (20 to 24 days/ha) for coop members and from 7 days to 9.5 days/acre (17.5 to 24 days/ha) for non-coop members.

The threshing of improved varieties has also increased labor requirements. In 1967 about 4.5 man-days per acre (11 man-days/ha) were needed for non-improved varieties while about 9.0 man-days per acre (23 man-days /ha) were needed for improved varieties. (Hoque, 1970)

Use of Fertilizer

Thus far, this discussion has dealt mainly with the change in the use of labor inputs with the introduction of improved varieties. There has also been major changes in the use of purchased inputs, such as fertilizer and insecticides.

Usually twice as much fertilizer was used to grow improved rice varieties as to grow non-improved varieties as shown in Table 1.10. (Winter Crop Cutting Surveys, 1966, 1967, 1969, 1970, raw data) Also total investments in fertilizer by cooperative members have been significantly larger than by non-members. When growing improved varieties cooperative members used about 3/4 of their total fertilizer investment on commercial fertilizer while non-members used only 2/3 of their fertilizer investment on commercial fertilizer. Cow dung is usually available from a farmer's own animals at no cash cost while cash purchase of commercial fertilizers (oil cake, urea, potash, and phosphate) is required. Cooperative members thus made both proportionately larger cash investments as well as larger total investments for fertilizer than non-members.

Table 1.10 Value of Fertilizer Used Per Land Area, 1966-1970

		1966		1967		1969		1970	
		Value	%	Value	%	Value	%	Value	%
Improved Rice									
Coop									
Cow dung	Rs/acre	35.80	43	19.30	24	32.20	24	31.20	29
	$/acre	7.52		4.05		6.77		6.56	
	$/ha	18.58		10.02		16.72		16.20	
Commercial	Rs/acre	47.40	57	59.89	76	94.04	76	78.61	71
	$/acre	9.96		12.58		19.76		16.52	
	$/ha	24.61		31.09		48.82		40.81	
Total	Rs/acre	83.20		79.19		126.29		109.81	
	$/acre	17.48		16.68		26.52		23.08	
	$/ha	43.19		41.11		65.54		57.01	
Non-Coop									
Cow dung	Rs/acre	---	--	17.05	33	31.40	32	37.80	34
	$/acre	---		3.58		6.60		7.94	
	$/ha	---		8.85		16.30		19.62	
Commercial	Rs/acre	---	--	34.32	67	68.32	68	73.22	66
	$/acre	---		7.21		14.35		15.38	
	$/ha	---		17.82		35.47		38.01	
Total	Rs/acre	---		51.37		99.72		111.02	
	$/acre	---		10.79		20.95		23.32	
	$/ha	---		26.67		51.77		57.63	
Non-Improved Rice									
Coop									
Cow dung	Rs/acre	20.40	50	17.70	37	26.50	35	23.10*	43
	$/acre	4.29		3.72		5.57		4.85*	
	$/ha	10.60		9.19		13.76		11.99*	
Commercial	Rs/acre	20.87	50	30.32	63	49.27	65	30.23*	57
	$/acre	4.38		6.37		10.35		6.35*	
	$/ha	10.83		15.74		25.58		15.69*	
Total	Rs/acre	41.27		48.07		75.77		53.33*	
	$/acre	8.67		10.09		15.92		11.20*	
	$/ha	21.43		24.93		39.34		27.68	
Non-Coop									
Cow dung	Rs/acre	11.70	56	13.00	47	10.45	53	22.20*	28
	$/acre	2.46		2.73		2.20		4.66*	
	$/ha	6.07		6.75		5.43		11.52*	
Commercial	Rs/acre	9.26	44	14.81	53	9.08	47	56.95*	
	$/acre	1.94		3.11		1.91		11.96*	
	$/ha	4.81		7.69		4.71		29.56*	
Total	Rs/acre	20.96		27.81		19.53		79.15	
	$/acre	4.40		5.84		4.11		16.62	
	$/ha	10.80		14.44		10.14		41.08	

* These values were derived from survey data containing less than four observations.

Increased diversification has occurred in the types of fertilizer used. For example in 1966, 7% of the coop members and 54% of the non-members used no fertilizer at all, with only 15% of the coop members and 6% of the non-members used both cow dung and all four of the commercial fertilizers. In 1970 everyone used some type of fertilizer. Seventy-nine percent of the coop members and 74% of the non-members used all five types of fertilizer.

Use of Insecticides

The use of insecticides has increased significantly with the introduction of improved varieties. In 1966, 53% of the coop members and 85% of the non-members did not have a pest attack and did not apply an insecticide. Of the cooperative members who did have a pest attack, 20% sprayed before the attack, 7% after the attack and 17% both before and after the attack. In 1970 only 1% of the coop members and 2% of the non-members did not have a pest attack and did not apply an insecticide. Twenty-five percent of the coop members and 12% of the non-members sprayed but did not have an attack. Thus, in 1970 only 26% of the coop members and 14% of the non-members were free of a pest attack. Of those who did have an attack, 37% of the coop members and 38% of the non-members sprayed after the attack. Twenty-seven percent of the coop members and 37% of the non-members sprayed both before and after the attack.

The average number of times the fields were sprayed has also increased. Between 1966 and 1969 the number increased from 1.5 to 2.75 applications per crop for those who sprayed after the attack. It increased from 1.2 to

1.9 applications for those who sprayed before the attack. And it increased from 2.25 to 3.25 applications per crop for those who sprayed both before and after a pest attack.

Farm Size and the Improved Varieties

In examining the relation between farm size and use of improved varieties data is available for both cooperative members and non-members as shown in Table 1.11. (Winter Crop Cutting Surveys, 1966, 1967, 1969, 1970, raw data)

Table 1.11 Distribution by Farm Size of the Number of Persons Growing Winter Crops

(1) Farm Size in		Cooperative Members (2) % Coop-members with given farm size	(3) Of members growing winter crop, % with given farm size				Non-Members (4) % non-members with given farm size	(5) Of non-members growing winter crop, % with given farm size			
acres	hectares		1966	1967	1969	1970		1966	1967	1969	1970
nil	nil	2	--	--	3	2	24	--	2	7	4
0-1	0-0.4	12	22	11	11	18	41	16	23	22	27
1-2	0.4-0.8	43	36	33	41	32	13	41	42	32	22
2-3	0.8-1.2	18	19	29	11	11	12	30	20	15	26
3-5	1.2-2.0	16	10	18	24	19	7	13	10	24	15
over 5	over 2	8	3	8	8	18	3	3	2	2	5

Ideally, if benefits from growing the new varieties were to be obtained equally by persons from all farm sizes, the distribution of farmers in each size growing winter crops would be the same as the distribution of farm sizes. For example in 1966, 43% of the cooperative members had a farm size of from 1 to 2 acres (.4 to .8 ha) while only 36% grew winter crops, instead of 43%. Similarly for non-members, values under heading 5 would equal that under heading 4 if benefits were equal. It must be emphasized that the estimates of Table 1.11 are only approximate, but they do give at least some indication of the trends in the use of winter cropping by farmers.

On closer examination of these data it would appear that for cooperative members, farm size had a fairly negligible effect on who is able to grow a crop. Thus, the cooperative was fairly successful in distributing the benefits of winter irrigation among all of its members regardless of farm size. Even the landless and near landless cooperative members are represented in winter irrigation in about the same proportion as they were represented in the total cooperative membership.

Unfortunately, this is not the case for non-members. While over 65% of the non-members had less than 1 acre (.4 ha) of land or were landless, no more than 31% of the non-members, who owned farms of this size, were able to utilize irrigation water to grow a winter crop in any one year. It is important to note, however, that this percentage was increasing each year. The farmers who seemed to benefit the most were those having from one to five acres (.4 to 2 ha), since more than the proportionate share of these farmers were able to grow winter rice crops. Actually it is the one to two acre (.4 to .8 ha) farmers who seem to have used winter crops in a higher proportion in comparison to their number than farmers with any other farm size.

What is the relation between size of farm and the percentage of farmers' land which is winter cropped? Several observations may be made using Table 1.12. (Winter Crop Cutting Surveys, 1966, 1967, 1969 1970, raw data)

Table 1.12 Percent of Land Owned which is Winter Cropped

Farm Size		Coop Members				Non-Members			
acres	hectares	1966	1967	1969	1970	1966	1967	1969	1970
0-1	0-0.4	80	60	195*	208*	--	--	58	77
1-2	0.4-0.8	53	50	77	79	--	--	53	55
2-3	0.8-1.2	46	56	75	66	--	--	23	59
3-4	1.2-1.6	25	65	66	70	--	--	38	23
4-5	1.6-2.0	--	22	51	47	--	9	25	66
over 5	over 2	--	48	60	56	--	--	--	25
Average		44	53	68	67	--	9	42	53

* Numbers larger than 100 are the result of these persons renting land in addition to the land they owned.

First, the small farmers, both coop members and non-members, irrigated a larger proportion of their farm land than larger farmers. The absolute acreage under cultivation, however, increased with increasing farm size. Second, cooperative members had a much larger proportion of their farm land under winter irrigation than non-members. Also, cooperative members with small land holdings of less than one acre (.4 ha) had a definite advantage over non-members with this same land holding in their ability to rent land and thus increase their cultivated acreages.

In only one year, 1970, was there a significant relationship between farm size and yield as shown in Table 1.13. (Winter Crop Cutting Surveys,

Table 1.13 Average Yield of Improved Varieties for Different Farm Sizes

Farm Size acres	hectares	Coop Members 1966	1967	1969	1970	Non-Members 1966	1967	1969	1970
0.0	0.0								
md/acre		----	----	44.62*	59.00*	----	----	50.57	45.16
lb/acre		----	----	3670	4852	----	----	4159	3714
kg/ha		----	----	4112	5438	----	----	4661	4162
0-1.0	0-.4								
md/acre		39.14*	32.41*	39.92	48.40	----	----	34.63	41.23
lb/acre		3219	2665	3283	3980	----	----	2648	3391
kg/ha		3607	2987	3679	4461	----	----	2967	3800
1-2.0	.4-.8								
md/acre		25.85*	48.72	43.06	45.42	----	----	37.27	43.90
lb/acre		2126	4007	3541	3735	----	----	3065	3610
kg/ha		2382	4490	3968	4186	----	----	3435	4046
2-3.0	.8-1.2								
md/acre		44.13*	34.43	45.28	43.61	----	----	46.92	45.61
lb/acre		3629	2832	3724	3586	----	----	3859	3751
kg/ha		4067	3173	4173	4019	----	----	4324	4203
3-4.0	1.2-1.6								
md/acre		31.48*	56.19	45.06	45.72	----	----	42.09	39.51
lb/acre		2589	4621	3706	3760	----	----	3461	3249
kg/ha		2901	5179	4153	4214	----	----	3879	3641
4-5.0	1.6-2.0								
md/acre		----	31.75*	49.37	59.51	----	33.20*	49.67*	54.70
lb/acre		----	2611	4060	4894	----	2730	4085	4499
kg/ha		----	2926	4550	4585	----	3060	4578	5041
over 5	over 2								
md/acre		----	34.93	45.30	53.58	----	----	----	50.66
lb/acre		----	2873	3725	4406	----	----	----	4166
kg/ha		----	3219	4175	4938	----	----	----	4669
Level of Significance		.79	.255	.563	.01			.172	.059

* These values were derived from survey data containing less than four observations.

1966, 1967, 1969, 1970, raw data) Even then, it was the farmers with one to four acres (.4 to 1.6 ha) whose yields seemed to be lower than the others. It is evident from this table that the small land holder with less than 1 acre (.4 ha) could effectively compete in the production of improved varieties with those with larger land holdings. Although evidence is inconclusive it does appear that larger land holders, those over 4 acres (1.6 ha) did on the average, have somewhat higher yields than persons with smaller land holdings. However, this does not appear to be cause for concern since persons with all sizes of land holdings adopted the improved varieties at about the same rate. Thus, farmers of no single land holding size derived benefits from the improved varieties at the exclusion of the others.

1.6 MECHANIZATION IN DEVELOPMENT PROGRAMS

Based upon their ability to use improved rice varieties the inclusion of even very small farmers, those with less than 1 acre (.4 ha), in agricultural development programs appears justified. Therefore, a more detailed discussion of the place mechanization has in these development programs will be given. In Bangladesh, rural landless laborers account for a significant portion of the rural population (15% in the Comilla Thana). Thus, any mechanization which displaced this rural labor would appear to be undesirable. If consideration is given to these two groups, criteria for evaluating mechanization can then be stated as follows: To be justified, the introduction of agricultural mechanization should 1) increase hired labor requirements or 2) help the small farmers, those with less than two acres (.8 ha), become more self-sufficient. As an example of the application of this criteria, consider mechanized irrigation. Mechanized irrigation, especially when used with improved rice varieties has reduced the farm size needed to provide a subsistence income to a family, thus has been of benefit to the small farmer. It has also substantially increased hired labor employment during the winter season when this labor would otherwise be idle. Thus it has benefited the rural landless laborer. Since mechanization in the form of mechanized irrigation meets both criteria it appears to be appropriate for consideration as a part of agricultural development programs. The appropriateness of mechanization for other crop production operations will next be considered.

Tillage

Tillage in Bangladesh has traditionally been performed by a pair of bullocks working with a wooden plow. Essentially no tillage has been performed by a man and a hoe. Farmers without bullocks rented them from other farmers. In the Comilla Thana only 8.2% of the farmers with less than one acre (.4 ha) and 26% of the 1 to 2 acre (.4 to .8 ha) farmers owned a pair of bullocks in 1964 (Research and Survey Bulletin No.1, 1964). Thus, the large majority of small farmers depended upon renting the source of power to perform their tillage.

The Comilla Thana attempted to supplement the bullock power by introducing tractors. Tractors reduced the total time required for tillage from 11.92 days/acre (29.45 days/ha) when bullocks were used alone to 5.45 days/acre (13.47 days/ha) when tractors were used in addition to bullocks.

Bullocks were not completely replaced in the tillage operation since tractors were used only for initial tillage and bullocks were still used for a final leveling and puddling of the soil before the crop was planted.

The human labor required for tillage was 6.18 man-days/acre (15.27 man-days/ha) when only bullocks were used and 3.16 man-days/acre (7.81 man-days/ha) when tractors supplemented bullocks. Table 1.14 indicates that over 70% of the labor used in the tillage operation was family labor. Tillage provided only 2% and 5% respectively, of the total hired labor used in growing improved and nonimproved rice. Thus, hired labor use in tillage was small. Any reduction due to tractor use would be negligible in comparison to total hired labor requirements. Actually, persons using tractors used more total hired labor. Persons using the tractors hired 56.45 man-days/acre (139.49 man-days/ha) of labor compared to 51.78 man-days/acre (127.95 man-days/ha) for bullock users when improved varieties of rice were grown and 35.75 man-days/acre (88.34 man-days/ha) compared to 34.49 man-days/acre (85.22 man-days/ha) when nonimproved varieties were grown. Thus, in the Comilla Thana, tractor mechanization neither significantly increased nor decreased hired labor.

The second criterion, the benefits of tractor mechanization to the small farmers will next be considered. The distribution by farm size of persons using tractors for tillage and those using only bullocks for tillage indicates that 57.4% of all tractor users had farm sizes of less than 2.0 acres (.8 ha), while 53.5% of the bullock users had farms of less than 2.0 acres (.8 ha). Thus, a larger proportion of the tractor users had

Table 1.14 Family and Hired Labor Utilization in Rice Production

Type of Rice	Mandays of labor /acre	Mandays of labor /ha	% of labor Hired	% of labor Family	% of total hired labor in each operation	% of total family labor in each operation	% of total labor in each operation
Tillage							
Improved	4.75	11.74	28	72	2	15	6
Nonimproved	5.80	14.33	30	70	5	18	11
Fertilize							
Improved	6.00	14.83	66	34	8	9	8
Nonimproved	5.05	12.48	61	39	8	8	8
Transplant							
Improved	18.00	44.48	83	17	28	15	24
Nonimproved	17.52	43.29	78	22	41	19	32
Weed							
Improved	20.53	50.73	74	26	29	24	28
Nonimproved	13.26	32.77	63	37	15	14	15
Insecticide							
Improved	1.92	4.74	44	66	1	4	2
Nonimproved	1.23	3.04	31	69	1	2	1
Harvest							
Improved	15.23	37.63	82	18	23	13	20
Nonimproved	13.16	32.52	68	32	27	20	24
Threshing							
Improved	8.96	22.14	51	49	9	20	12
Nonimproved	4.87	12.03	18	82	3	19	9
Total							
Improved	75.39	186.29	70	30	100	100	100
Nonimproved	50.89	125.75	60	40	100	100	100

small farms than did bullock users. One reason for this is that 83% of the rice growers who did not own bullocks had farms of less than 2 acres (.8 ha). Of the farmers without bullocks, 49% used the tractors. Thus, the tractors were an important power source for the small farms without bullocks. In addition, during the irrigated season the farmers without bullocks who used the tractors cropped a larger proportion of their farms, 60% compared to 47% for those who rented bullocks. For farmers who owned bullocks, the proportion of their farms which was cropped was nearly equal when bullocks were used for tillage, 48%, as when tractors supplemented the bullocks, 49%. Thus, the tractors have benefited the small farmers without bullocks who owned, on the average, 1.35 acres (.55 ha) of land, by increasing his cultivated acreage, while not giving this same advantage to larger farmers with bullocks who owned, on the average, 3.0 acres (1.21 ha) of land.

In the Comilla Thana tractors have apparently filled a power shortage for the tillage operation. Between 1965 and 1969 when the tractors were gaining a fairly widespread use, the value of livestock and therefore the number of work animals, on farms measured in constant prices, remained constant. Thus, farmers continued to own bullocks even though they supplemented this source of power by renting the tractors. The inadequacy of bullock power was especially apparent during the winter irrigation season of 1969 when 25% of the rice growers who owned bullocks also rented the tractors to help perform their tillage.

To summarize, tractors have seemed to displace a negligible amount of hired labor. They have been of special benefit to farmers who owned no bullocks. They have also been used by farmers who owned bullocks and have supplemented rather than displaced the bullock labor. During the irrigation season, tractors have increased cropped acreage for the small farmers while not doing so for the larger farmers.

Fertilization

Fertilization activities provided 8% of the total hired labor used in growing both improved and nonimproved rice varieties as shown in Table 1.14. Over 60% of the labor used in this operation is hired. In Bangladesh all fertilizer is spread by hand. Precise fertilizer placement has not appeared necessary for rice production with flooded fields. Neither labor generation nor any apparent benefits to farmers would result from the introduction of machines to perform this operation.

Transplanting

The transplanting operation was the largest employer of hired labor when nonimproved rice varieties were grown and the second largest when improved varieties were grown. Table 1.14 shows that 28% and 41% of the total hired labor used in producing improved and nonimproved varieties respectively, were employed in the planting operation. Considering the labor used in a single operation, transplanting employs a larger per cent of hired labor than any other operation; 83% for improved varieties and 78% for nonimproved varieties. Transplanting is presently performed by hand and as seen above is a major employer of hired labor.

Weeding

The weeding operation was the leading employer of hired labor for improved varieties of rice accounting for 29% of all hired labor and the third largest employer for nonimproved varieties, accounting for 15% of all hired labor as shown by Table 1.14. Hand weeding and weeding with a one-row push type weeder were the methods of performing this operation. The use of the push type weeder appears to have been labor generating in Bangladesh. One reason for this was that even though the push type weeder was more efficient, it could cover a larger area per day, the weeding operation was performed more often when it was used because the work was less tedious. Also, hand weeding was still required within the row.

Insecticide Application

The application of insecticide, as shown by Table 1.14, accounted for only 1% of the hired labor used in growing either improved or nonimproved rice. Labor use in this operation is negligible compared to the total. It appears that mechanization of this operation should be based upon the effectiveness of insect control rather than upon labor generation.

Harvest

The harvest operation was the third largest employer of hired labor when improved varieties are grown, accounting for 23% of the total hired labor. It was the second largest employer when nonimproved rice varieties were grown accounting for 27% of total hired labor. As shown in Table 1.14 harvesting ranked second to transplanting in the proportion of hired labor used in performing the operation. With improved varieties, 82% of the harvesting labor was hired and with nonimproved varieties 68% was hired. The harvesting is done with a hand sickle and transported manually to a threshing floor. Thus the harvesting operation accounted for a substantial portion of hired labor employed in growing rice.

Threshing

Threshing was an operation where mechanization was important in labor generation. The traditional method of threshing nonimproved rice was to tread animals over the rice and straw. This resulted in the operation being performed mainly by family labor, 82%, with the bullocks being the major source of power. Because the improved rice varieties could not be easily separated from the rice stalk, threshing by animal was in many cases no longer possible. An efficient method of threshing the improved varieties was the pedal operated drum thresher. This machine, however, required as many as 6 men to operate. Two persons pedaling and threshing, two persons discarding used rice bundles and two persons getting unthreshed bundles. Since more people were required to operate the thresher and human labor was substituted for animal labor, substantially more human labor was required. Man days/acre of human labor increased by 84% when the pedal drum thresher was used. Also, more of this labor, 51%, was hired. The contribution of the threshing operation to total hired labor was 9% for improved varieties compared to only 3% for nonimproved varieties.

CHAPTER 2

2.0 INTRODUCTION

Tractor mechanization for the tillage operation was found in Chapter One to be non-labor displacing and of benefit to small farmers with less than 2 acres (.8 ha) of land in the Comilla Thana, Bangladesh. In the Comilla Thana a cooperatively owned and operated tractor and machinery hire center was used to provide this tillage mechanization.

Cooperative mechanization, however, is not the only method by which tractor mechanization has been made available to farmers in developing countries. The services of tractors and machinery have been made available to farmers under many different arrangements of ownership and custom operation in various parts of the world. Some of the more common arrangements are:

1. Private ownership and operation of tractors and equipment.
2. Government owned and operated tractor and machinery hire centers.
3. Group ownership of a tractor and/or machinery by neighboring farmers.
4. Ownership by a single farmer that does his own work and also does custom work for others.
5. Cooperatively owned and operated tractor and machinery hire centers.

These various arrangements for tractor and machinery ownership and utilization in developing countries will be discussed in this chapter. The appropriateness of these ownership patterns for the conditions such as those in Bangladesh will also be discussed.

2.1 PRIVATE OWNERSHIP

The first method of introducing mechanical power to be considered is the private ownership and use of mechanization on a farmer's own farm. Private ownership of a tractor and equipment by a farmer appears to be the ideal for maximum independence. Unfortunately, private ownership tends to provide an incentive for farmers to increase their land holdings through either purchase or rental of additional land and often reduces the number of tenants on farms. Thus, this method of mechanization should be considered mainly in countries where the industrial and service sectors are able to absorb the labor displaced by this mechanization. Gotsch, in reference to Pakistan (West Pakistan) has written, "Nearly 50% of the arable area is cultivated by tenants of one sort or another. The majority (75%) are small farmers with less than 12.5 acres, who operate their holdings with a single pair of bullocks and the labour of their families. A mechanization programme that relegated this group to the status of landless labourers would undoubtedly produce a significant and undesirable alteration in the social structure of the rural communities." (Gotsch, 1973) This displacement of tenants when mechanization is privately owned by large farmers seems to be substantiated by a survey made by Donaldson of 200 farms in West Pakistan which purchased 35 to 65 hp four wheel tractors in 1967. Donaldson writes, "The most striking change following the introduction of a tractor was the growth in the average size of farms by a factor of 2.4 - from 45 acres to 109 acres per farm for the survey as a whole. Only 23 of the 200 survey farms did not increase their acreage. Land previously rented out accounted for 42% of this additional land." (Donaldson, 1973)

The important criteria that mechanization in countries which have a surplus of human labor be labor generative and of benefit to small farmers was not met in the case of West Pakistan. The policies of the Pakistan government including cheap credit, artifically high crop prices, and the availability of foreign exchange for the import of tractors, were instrumental in encouraging tractor mechanization by the large landowners at the exclusion of others. Thus, other countries which are considering tractor mechanization through the private ownership of equipment should carefully evaluate the effects this mechanization will have on their rural communities.

The results of private ownership of 35 to 65 hp tractors in Pakistan are similar to the private ownership of 2 wheel power tillers in Bangladesh. Donaldson reported on the Agricultural Development Bank of Pakistan's (ADBP) farm survey of power tiller owners made between 1968 and 1970. (Donaldson, 1970) This survey showed no significant increase in cropping intensity on farms which had purchased power tillers, but did show up to a 20% increase in acreage cropped. The source of these additional acres was not explained but was known not to be grazing or forage land. It was therefore assumed that his increased acreage came from the farmer bringing more land under his direct control, with less use of sharecroppers. The ADBP survey also showed an average saving of about 200 man-days of labor per year when a tiller was introduced onto a farm of over

20 acres (8.1 ha). Finally, the purchase of a power tiller was based upon a 20% cash deposit and a loan for the other 80% was advanced only with a land mortgage as security. This required a farmer to mortgage between 4 and 5 acres (1.6 and 2 ha) to cover the loan for a tiller. Less than 1/4 of the farmers in Bangladesh have farms large enough that they could supply sufficient security to purchase a tiller under these conditions. Thus, tractor purchases were limited to large landholders. The criteria that mechanization generate a demand for hired labor or be of benefit to small farmers was not met in this power tiller program.

2.2 GOVERNMENT OWNED TRACTOR HIRE CENTERS

There are many countries that have attempted to operate government owned tractor hire services. Two examples, Nigeria and Ghana, will be cited here.

Stout reported that in Nigeria the tractor rental services were organized within the Ministry of Agriculture and mainly tied to Ministry of Agriculture production schemes. Demand for tractor services was seasonal and limited to seedbed preparation for a small range of crops. The average output per tractor tended to be low, with tractors operating about 300 hours per year. The Ministry of Agriculture charged $5.25/acre ($13.00/ha) for plowing. However, the costs of operating the tractors exceeded this charge by $1.36/hour if depreciation was not included and costs exceeded charges by $2.24/hour if depreciation was included.

Actually, the tractor hire charges just met the direct operating cost of the tractors.

The tractors were rented by individual farmers. The average farm under mechanical cultivation was 10 acres (4 ha) in size. The farms were located an average of 12 to 15 miles (20 to 25 kilometers) from the tractor-hire unit and about 6 miles (10 kilometers) from the nearest road.

Farmers generally were well satisfied with work done by the tractors despite difficulty in obtaining timely service. Farmers believed that tractor's tillage increased their income by alleviating the planting season bottleneck and providing better tillage which resulted in larger yields (54% more on all crops). During the peak demand periods, farmer demand for services exceeded the working capacity of the tractor-hire units of the government. The inability to meet the demand for tractor services was partially caused by many workshops being short of parts for timely repairs and maintenance of the tractors and equipment. The situation was further aggravated by accelerated wear due to inexperienced and undertrained drivers (Stout, 1971).

In Ghana Cervinka reported that the tractor hire services were also organized within the Ministry of Agriculture. The management of tractor operations was complicated, being organized on three levels. The headquarters office was located in the capital city and regional and district headquarters were located throughout the country. The Agricultural officers in the districts, where the tractor work was performed, were usually trained in farm mechanization. However, even though they were highly qualified, little of their efforts were spent in the actual operation of the tractor hire service. Most of their time was spent preparing forms and reports required by the regional and national headquarters offices.

The tractors' utilization was low with tractors on the average being operated about 425 hours/year. The tractors were used mainly for primary tillage (70%) and transport (30%). Tractors were hired mainly by small farmers with land holdings of only a few acres. The tractors worked on farms within a radius of 15 to 25 miles (24 to 40 kilometers) from the district tractor depots. Supervision of tractor operators' work on farms was very ineffective. A major reason for the inefficiency of the tractor hire program appeared to be related to the supervisors and operators having no direct responsibility for running the tractor operation economically. (Cervinka, 1969)

Based upon these examples some general observations concerning government operated tractor hire services can be made. First, these tractor hire services have been used mainly for tillage. This has minimized the displacement of hand labor, since few countries utilize hand labor for the tillage operation. Even in countries where hand labor is used for tillage, total employment of labor in production of the crop usually increases with mechanical tillage since more land is brought under cultivation. Second, the tractor hire services have mainly been used by the smaller land owners. Finally, the services have been available at reasonable prices. Thus, government tractor hire services have benefited the small farmers and have not tended to displace labor so they appear to be

an appropriate form of mechanization. However, there are several major shortcomings with government operated hire services.

First, these types of mechanization programs seldom operate efficiently because of the bureaucratic organizational tendencies that tend to accompany programs under direct government control. Persons within the tractor hire service organization seldom are given incentives to operate the service efficiently. Usually, few of these workers have farm backgrounds thus, they do not realize or empathize with the farmers' needs for a reliable and timely tractor hire service.

2.3 GROUP OWNERSHIP BY NEIGHBORING FARMERS

Japan illustrates the application of group ownership by neighboring farmers. Japan, a country consisting of small farms (average is about 2.5 acre (1 ha) each), is noted for having designed mechanical equipment for ownership by small farmers. In the mid-1950's only 3% of farmers possessed power tillers but one decade later in the mid-1960's over 50% of Japan's 6 million farmers possessed them. Even 1/3 of the farmers with less than 1.25 acre (0.5 ha) of farm land had 5 to 7 1/2 hp power tillers and those with more than 3.7 acre (1.5 ha) averaged more than one power tiller per farm. (Mukumoto, 1969)

In the 1960's transplanters, combines and dryers were designed and manufactured in Japan for the small farmers. These machines were quite sophisticated and expensive. The increasing scarcity and cost of agricultural labor, however, forced farmers to purchase them. Almost all of these machines had greater capacity than needed by the 2.5 acre (1 ha) farmer even with the seasonal one-crop production pattern of Japan. Thus, to increase the utilization and to overcome the financial constraint in purchasing the equipment, often a group of three or four farmers would buy one or more of the machines together and operate them cooperatively. Similarly with 10 hp power tillers and larger 4-wheel tractors of which there were over fifty thousand in use in Japan by the end of 1966, about 10% were jointly owned by two or more farmers.

Joint ownership by small farmers was successful in Japan. However, there appears to be several major problems concerned with its application in less developed countries. First, although farms in Japan are small, farmers are quite prosperous by world standards. Under these conditions, combining the financial resources of two to four persons was sufficient to purchase mechanical equipment. In Bangladesh the combined financial resources of many more small farmers would be required in order to purchase even a small power tiller. Also the subsistence or below farmers lack any financial resources to invest. Thus they would be excluded from the mechanization program. Second, two or three persons can share the operation of the machine, as well as the operating, repair, and maintenance costs quite easily. As more persons are added to the ownership, however, it becomes much more difficult to schedule the machine's operation and to assess the machine's costs among the individual farmers.

Third, machines have been used by most farmers in Japan for more than two decades. They have developed a competence in machine operation and

therefore each farmer can usually operate the jointly owned machine effectively. In many developing countries farmers have not yet developed such a competence. Specially trained machine operators would be required to operate the machine. Selecting the person who would learn to operate the machine and arranging to pay him to operate it could pose a problem because of the large number of farmers involved.

A possible solution to these problems is a formal organization of the farmers. This suggests a cooperative owned and operated mechanization service. This type of mechanization program is discussed in section 2.5.

2.4 INDIVIDUAL OWNERSHIP WITH CONTRACT HIRING

Thailand and Malaysia illustrate the application of individual ownership combined with contract hiring. Chancellor made an extensive study of these types of operation. He reported that in both Malaysia and Thailand the traditional forms of farm power have proved inadequate for the new areas of agricultural development. Rice production has been encouraged in Malaysia and the hand and animal powered methods have not been fast enough to prepare land for the second crop. In Thailand neither the work animals nor the traditional implements were strong enough to deal with the more firm upland soils where diversification was promoted.

In both countries government sponsored activities in the promotion of tractor utilization was small in proportion to the level of private commercial activities in this field. Government policies and government sponsored activities, however, were significant in promoting the tractor

utilization program. The following government activities have been very important:

1. The maintenance of stable, internationally exchangeable currencies by both governments has attracted outside manufacturers and sales firms.

2. Specific programs of agricultural development provided background circumstances and some of the key elements required for new, highly productive activities by farmers. Research on maize production in Thailand and the development of irrigation and drainage systems in Malaysia are examples.

3. Government sponsored tractor stations initially introduced farmers to the capabilities and costs of tractor use as well as providing a basis for the development of the tractor contractor system.

In both countries the essentials for this changing technology of mechanization were present. The markets provided the production incentives for farmers. And the inadequacy of traditional tillage methods created by the double-crop rice program in Malaysia and diversified upland crop production in Thailand provided the demand for new methods.

Tractor sales agents, their merchant colleagues selling fertilizer and seeds, and local equipment manufacturers, all of whom operated in economies where purchases from and remittances to any part of the world could be made at their own discretion, took the initiative in filling this local demand for supplies and equipment. Four-wheeled tractors in the 40-70 horsepower size range were mainly imported into Thailand while power tillers under 10 horsepower were mainly imported in Malaysia. As an illustration of the response to the introduction of this mechanization, in Thailand in 1960, tillage for field crops was being done almost exclusively by traditional animal and hand powered methods. By 1968, however, it was estimated that tractor tillage (on single-pass basis) was being applied to an area equivalent in size to 55% of the total land in annual crops. A similar figure for Malaysia was 48%.

The tractor services were hired mainly by farmers for tillage. Disc harrow and disc plows were used in Thailand and rotary tillers were used in Malaysia. Tillage in Thailand was done mostly in dry soils and in Malaysia in wet soils.

One reason that farmers chose to hire tractor service was connected with the faster work of the tractor, which saved them 6-10 man-days per acre (14.8-24.7 man-days/ha) per season. The time saved by hiring tractors however, was used elsewhere. Agricultural intensification that did not displace labor was reverted to by 65% of the farmers in Thailand and 75% in Malaysia. In 30% of the cases the added income covered the cost of hiring tractors.

A second reason for the use of contract hiring services was that in Thailand farmers found tractor tillage cheaper than previous methods, and in Malaysia farmers noted an improvement in the quality of tillage. Charges were usually levied according to the area served or other measures of work accomplished. Service rates were generally higher in Malaysia than in Thailand ($0.069 vs $0.038 per rated horsepower hour for 4-wheel tractors) but were decreasing in both countries (6% per year in Thailand and 3% per year in Malaysia). Farmers valued the services at about 150% of the rates charged and at least half valued the tractor tillage input more strongly than they did fertilizer.

The farmers who used the tractor service of contractors tended, in Thailand to have larger than average land holdings, 23 vs 9 acres (9.3 vs 3.6 ha) and in Malaysia to have average sized holdings, 5 to 6 acres (2 to 2.4 ha). Farmers in both countries had a strong desire to purchase a tractor or power tiller for use on their own and neighboring farms. One reason for this may have been that in only about one-half of the cases did the tractor arrive on schedule. Irregularity was less of a problem in Malaysia than in Thailand. In Thailand 22% of the farmers had at least one experience in which the tractor failed to come at all.

Tractor owners in the vast majority of cases (80-90%) were farmers also. Their land holdings tended to be about twice the size of tractor hiring farmers. Most had hired tractor service for 3 or 4 years before they bought their tractors. These tractor-owning, farmer-contractors were primarily concerned with first serving their own farms. One of the main reasons for ownership by large farmers has been the method of purchase. The majority of tractors were purchased new, using credit arrangements. In Thailand, government loans were available to cover the amount of the down payment. However, the down payment (which averaged about 1/3 the sales price of the tractor) was in 2/3 of the cases obtained from the owners' own savings or those of his family. To select credit worthy customers the tractor distributor usually required that the customer provide a guarantor: a well-known person who would vouch for the customer's credit worthiness. In Malaysia the government loan usually covered the full price but the farmer had to have sufficient land to provide collateral for the loan. Thus, ownership of tractors in both Malaysia and Thailand was mainly limited to larger farmers who had the cash and collateral to make the purchases. Even ownership by larger farmers, however, did not mean that they could pay for the tractor without difficulty. About one-half of the tractor purchasers said that they were behind schedule on their payments.

Contract hiring of their tractor was considered by many farmers to be a necessary arrangement to help pay for the tractor. The rates contractors charged, however, were at a level which made tractor operation uneconomical for most owners. Only 44% reported making a profit. Over 94% of the owners in both countries, however, felt that they could not raise the price they charged for custom work as they were afraid the demand for their services would decrease.

Multiple drivers per tractor were common with a typical number being three in Thailand and two for 2-wheeled tractors in Malaysia. In slightly over half of the cases all drivers were related to the owner and in almost all cases at least one was so related. In about one-half of the cases the owner was a member of the driving team and in most other cases he made daily supervisory checks on operation. Many of the drivers, particularly in Thailand, had not received any training or supervised experience in tractor operation. Many of the owners were interested in training for their drivers. Most drivers in Thailand were paid by the month, while some, as well as the majority in Malaysia, were paid a proportion of the gross income from tractor service charges. Such proportions were about 20% for 4-wheel tractors and 30% for 2-wheel tractors.

Average work capacity for a 50 to 60 horsepower 4-wheel tractor was 0.725 acres per hour (.293 ha/hr) for a single pass with a 60-inch rotary tiller, 0.423 acres per hour (.17 ha/hr) with a 7-disc tiller on flat rice land and 0.73 acres per hour (.30 ha/hr) on rough upland fields. The common work rate for 2-wheel power tillers of 9 horsepower was 0.22 acres per hour (.09 ha/hr) for a single pass. The typical tractor age was 3 1/2 to 4 years.

Tractors in Thailand usually operated either 7 to 12 hours per day or 19 to 24 hours per day, with the latter being more common. In Malaysia 7 to 12 hours per day was the most usual arrangement. In Thailand, tractors were busy about 5 months per year, while those in Malaysia worked about 3 1/2 to 4 months per year. Annual hours of operation were about 1360 and 1040 for 4-wheel tractors in Thailand and Malaysia, respectively, while 2-wheel tractors in Malaysia operated about 400 hours per year. To accomplish this, the 4-wheel tractors traveled a typical maximum distance of 50 miles (80 km) from home, while 2-wheel tractors traveled about 7 miles (1.25 km) maximum. Traveling consumed 24 and 17 percent of their total time, respectively, for 4-wheel tractors in Thailand and Malaysia and 10% for 2-wheel tractors. Most tractors were being fully utilized during the periods of field tillage operations but there was little demand for services in off seasons.

Tractor breakdown was a problem particularly in Thailand where about 26% of the potential working time in the main season was lost due to this cause. In Malaysia it was 15% of the time. Annual repair costs in Thailand were also higher than in Malaysia. Implements were a major source of mechanically caused work stoppages in both countries. Generally, tractor owners managed minor repairs and some major repairs, however major repairs were usually done by local repair workshops or by tractor sales agents.

Most implements sold in Malaysia were imported while most sold in Thailand were, at least in part, locally made. These were supplied from many small workshops to agents for resales. The workshops also engaged in direct sales. Implement designs were usually copied from imported implements. Most sales agents had 3 or 4 mechanics, the majority of whom had received technical training through a central distributor program. Sales of parts amounted to about 20% of the tractor sales agents' income in Thailand. (Chancellar, 1970)

Based upon this information it seems that privately owned contractor hire services were biased in favor of meeting the tractor owners' needs and the needs of the larger farmers who rented the tractors. The privately owned contractor hire services have not appeared to be readily available to the very small farmers. Also, the stable and internationally exchangeable currencies in Thailand and Malaysia played an important part in developing private ownership with custom hiring. In countries where foreign exchange is very limited it would appear to be difficult to implement this type of mechanization successfully.

One method of making contract hiring services more responsive to the needs of the small farmers might be to revise the credit arrangements for purchasing tractors to be biased in favor of small farmers and the landless rather than against them. If a small farmer or landless person owned a tractor, he would mainly use the tractor to provide custom hire services to other farmers in order to supplement his income and pay for the tractor, rather than serving his own farm. This would have a two-fold advantage. First, it would provide the small farmer or landless laborer a source of employment in an entrepreneurial enterprise. Second, it would encourage a quality tractor hire service since the tractor owner's livelihood would depend upon his providing the tractor hire service effectively and efficiently. However, to make the contract hire service economically viable for the tractor owner and yet provide a reasonably priced service to the farmers would require that there be a specified number of persons offering contract hire services located in any given area. This would create the need for regulation of tractor sales.

Finally, the prior use of government operated tractor hire services in Thailand and Malaysia provided a basis for the development of the contract hire service. Whether contract hire services could have developed without this prior experience has not been determined.

2.5 COOPERATIVE TRACTOR MECHANIZATION

Irrigation and tractor cultivation were found to be complementary to one another in the Comilla Thana. Water was needed to soften the soil which becomes baked and extremely hard during the dry season. Tractor cultivation on the other hand, was desired to reduce the number of days required for land preparation. Thus, it contributed to the timely and efficient use of the irrigation facilities for crop production. A cooperative tractor hire service with both irrigation pumps and tractors thus became an integral part of the agricultural development scheme for the Comilla Thana.

Tractor mechanization was initiated by the Academy for Rural Development at Comilla early in 1960 with the procurement of two 35 horsepower tractors from the East Pakistan Agriculture Department. A few demonstrations were made for the farmers and rental fee of about $2.00/acre ($5.00/ha) was set. Soon thereafter, the farmers started requesting the tractors. The limited land holdings of 1-2 acres (.4-.8 ha) and extremely small field sizes of .1 to .4 acres (.04 to .16 ha) made effective use of the tractors quite difficult. Experience soon showed that farmers with adjoining fields needed to group together so that the tractors could be operated on a reasonably large area. The problem of maintaining field boundaries, which were earthen ridges, was solved by raising the implement when the tractor drove over them. One or more acres of land was thus tilled at one time and the identity of each farmer's plot was maintained. The groups clearly demonstrated the benefits of mutual cooperation and thus, contributed to the village cooperative movement in the thana. Two more 35-horsepower tractors were allocated to the Academy in 1961.

The Agriculture Department supplied a driver with each of the first four tractors. The experience with these tractor drivers from outside the thana was disappointing. They were reluctant to perform field operations and complained about working in the sun. They often returned from the villages early in the day, sometimes without having done any field work. The decision was soon made by the Academy to select potential drivers from among the young men of the villages and train them. The criteria set for the initial group of tractor drivers were that they must be:

1. Members of a village cooperative society.
2. Able to do all types of farm work.
3. Physically fit.
4. Educated

Following their training it was found that those with more education (the ability to read and write) seemed to be less physically fit to do the work. They were also less willing to do field work as some of them felt that, with their education, working in the field was below their status. Thus, when the next group of drivers was selected for training in late 1961, the only criteria were that the trainees be healthy, hardy, and already working in the field. Education was not considered. The subsequent driving performance of those who passed the course was found to be very good. Thus, it was concluded that an academic education was not a necessary requirement for tractor drivers.

This lack of education has led to some rather serious problems however. The illiterate drivers possessed only limited operational knowledge of the tractors and equipment. Many of them did not appreciate the significance of preventive maintenance and proper adjustment of the machines. The lack of maintenance and adjustment caused many breakdowns and shortened the working life of the tractor station machinery. Compulsory periodic retraining of all drivers was found necessary. Continual close inspection of driver performance by a competent supervisory staff member was also found to be a requirement.

Maintenance and Repair

Tractor maintenance and repair were severe obstacles to the effective operation of the cooperative owned equipment. This became particularly acute when 16 more 35-horsepower tractors were acquired in late 1961. There were initially only three maintenance people in the tractor station and their work was hampered by a lack of adequate tools, spare parts, and workshop facilities. There were few importers or suppliers of spare parts or equipment in the country. The tractors were often idled when even parts for minor repairs could not be obtained. It was thus decided that the machine station should have its own stock of spare parts and maintenance tools. In 1962 the Ford Foundation provided funds to build a workshop facility and to equip it with tools and spare parts. This facility substantially improved the effectiveness of the maintenance section of the tractor station as more timely repair of machines was possible.

The type and number of spare parts required for the machines, however, was not known. This resulted in the importation of large quantities of spare parts which were either not needed at all or not needed in the quantities imported. Also, many parts not imported were needed. As a result, delays were still common. Tractors were often idled from 6 months to one year while parts were being imported. However, the delays did occur less frequently. The first 20 tractors of the machine station were replaced by newer models in 1967, making about 80% of the old spare parts stock obsolete.

Repair cost expressed as a percent of the purchase price of the tractors for the first tractors owned by the tractor station is shown in Figure 2.1.

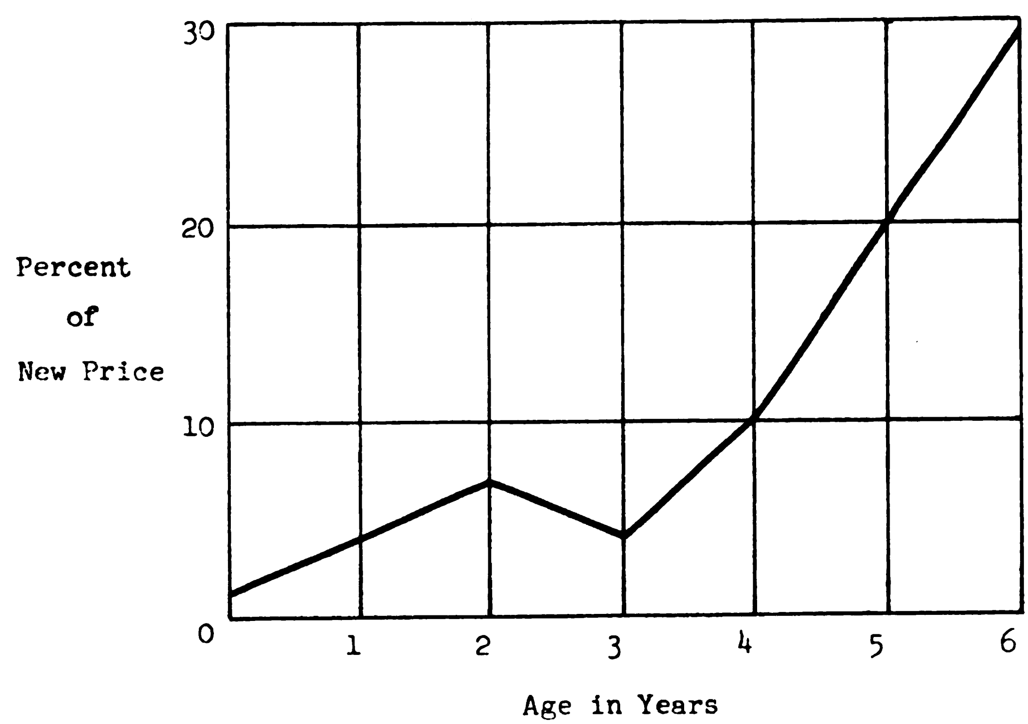


Figure 2.1 Tractor Repair Cost Each Year of Age Shown as Percent of Original Cost

This graph indicates a fairly steady increase in repair cost except for the fourth year of tractor operation. This drop in the fourth year may reflect an improvement in tractor maintenance and in staff performance at the tractor station. However, the general lack of preventative maintenance and the tractor misuse was reflected in the greatly accelerated cost of repairs during the last 3 years of the tractor's operational life at the machine station. The useful life of these tractors was about 7 to 8 years. During this period an average of 75% of the new cost was spent for the repair of each tractor. This resulted in an average repair cost of about 10% of the original tractor price each year. The life expectancy was thus about 25% less and cost of repairs were at least 100% more at Comilla than in the U.S..

Various tractor attachments experienced a short life and high repair costs. One example was the tractor mounted rotary tiller. The implements were used for preparation of rice land. The tractor station purchased 16 rotary tillers in January of 1968. These tillers were operated an average of only 250 hours a year but were discarded as worn out after two years in December 1969. Thus, the tiller had an average total operating life of about 500 hours. With an initial cost of about $700.00, the fixed costs alone amounted to almost $2.00 for each hour of operation. The tractor station rental price for tractor, driver and implement was only $1.50 per hour; thus, the rental price did not cover the fixed cost of the implement, let alone the fixed cost of the tractor plus operating costs.

Neglect and misuse by the drivers and mechanics was responsible for some of the shortened life of the tractors and machines. A significant portion was also attributed to the design and construction of the machinery. The rotary tillers were designed for operation under fairly dry conditions in temperate climates with moderate rainfall. The tillers were, however, operated in the flooded rice paddy fields under saturated soil conditions. The tillers proved unsatisfactory under these wet conditions. A different type of rotovator was purchased in 1970. It was hoped that this rotovator would prove to be better adapted to the flooded field conditions in which it was to operate.

Tractor Operation

The tractors have performed several types of work during the years. The work included tillage, hauling, rice hulling, pumping, blade work, mowing and winch operations.

Tractor use in the Comilla Thana is shown in Table 2.1. (10th Annual Report, 1969) There were from 14 to 38 tractors per year in the station from 1963 to 1969 (See Table 2.1). The number of tractors operated by the station at any one time varied from 14 to 26 with 16 to 20 being a typical number in operation. The number of tractors used for tillage varied from 6 to 18. For the first time, all the tractors were used for tillage during the year 1968-69. As few as six tractors were used for tillage during two of the years. This was less than a third of the tractors in the station during those years.

The number of days of cultivation showed an increasing trend for the six years except for 1965-66 when the number dropped to the lowest since the opening of the tractor station. Since 1966-67 the number of days of cultivation has increased substantially each year. The main reason for

Table 2.1 Tractor Use in the Comilla Kotwali Thana

	1963-64	1964-65	1965-66	1966-67	1967-68	1968-69
Total No. of Tractors in Station	14	38	26	20	28	17
No. of Tractors used in Cultivation	13	16	6	6	18	17
No. of Days of Cultivation	409	422	253	439	891	1019
Total Acres Tilled	2029	2521	1583	2628	4841	6154
Hectares Tilled	821	1020	640	1063	1959	2490
Acres Tilled Per Tractor	156	158	266	438	269	362
Hectares Tilled Per Tractor	63	64	108	177	109	147
Acres Tilled Per Day Per Tractor	4.96	5.97	6.23	5.98	5.44	6.00
Hectares Tilled Per Day Per Tractor	2.01	2.42	2.52	2.42	2.20	2.43
No. of Days of Hauling	1892	1564	2343	1530	1146	1119
No. of Days of Rice-Hulling	33	103	125	96	40	43
Total Days of Work	2334	2089	2721	2065	2077	2181

this increased tillage was the introduction of tractor mounted rotary tillers. Before 1968 the main emphasis was on dry land tillage with the disc harrow. This limited the use of the tractors for tillage to the dry winter months. Tillage was further limited during these dry months to those few days that followed a rain or to areas where there was irrigation.

The ground was baked too dry and hard at other times for cultivation. The use of tillers in saturated soils made possible the preparation of flooded rice land for the irrigated Boro crop as well as the late monsoon (Amon) season crop. Disc harrows continued to be used for dry land tillage during the Boro and Aus seasons. About half of the tillage days of 1968 (420 out of 845) were accounted for by the rotary tillers. Rotary tillers use increased to 60% (540 out of 903 days) in 1969.

The total acres tilled by the tractors showed much the same trend as the days of cultivation with large increases in both 1967-68 and 1968-69 (See Table 2.1). In 1968-69 the total acreage tilled was 6154 acres (2490 ha), which is approximately 8% of the 77,340 acres (31,300 ha) planted to crops in the Comilla Thana that year.

The area tilled per tractor showed an increasing trend throughout the years, with a maximum of 438 acres (177 ha) per tractor in 1966-67 (See Table 2.1). Only six tractors were used for tillage in that year but were used intensively. The acreage per tractor also reached a relatively high level in 1968-69 when there were 17 tractors in the machine station. The six acres (2.45 ha) tilled per day per tractor showed little change over the years.

Hauling has always been an important operation performed by the station's tractors. Table 2.1 shows that hauling accounted for a majority of the days of tractor work each year. Hauling reached a peak of 86% of the total days of work in 1965-66. Hauling was de-emphasized after 1965-66 and steadily decreased to 50% of the total days of work in

1968-69. This nearly 50% decrease from 2343 to 1119 days per year reflected the management decision in 1966 to reduce hauling.

Rice hulling was one of the lesser time consuming tasks performed by the tractors. Tractor use for hulling peaked at 125 days in 1965-66 and decreased steadily afterwards. This decrease was caused by the introduction of cooperative rice hulling mills in a number of villages throughout Comilla Thana.

The total number of tractor use days was highest in 1965-66 at 2721 days (Table 2.1). A severe drop was experienced in 1966-67 (2065 days). Total days of work increased slowly after 1966-67. The latest rise may be attributed to increased use of tractors for tillage, while the large number of days of work prior to 1966-67 can be attributed to the utilization of the tractors for hauling.

Tractor work distribution by month of the year is shown in Figure 2.2. Tillage work peaked three times during the years. Each peak corresponded to one of the cropping seasons. The largest peak was in the December-January irrigated season.

A correlation analysis was made between the various factors of Figure 2.2. The analysis showed correlation coefficients of -0.15 between hauling and tillage, -0.39 between repair and hauling, -0.63 between repair and tillage, and -0.66 between repair and tillage, and repair and total work. These negative correlations indicate that as one increases the other decreases. Tractors under repair during periods of

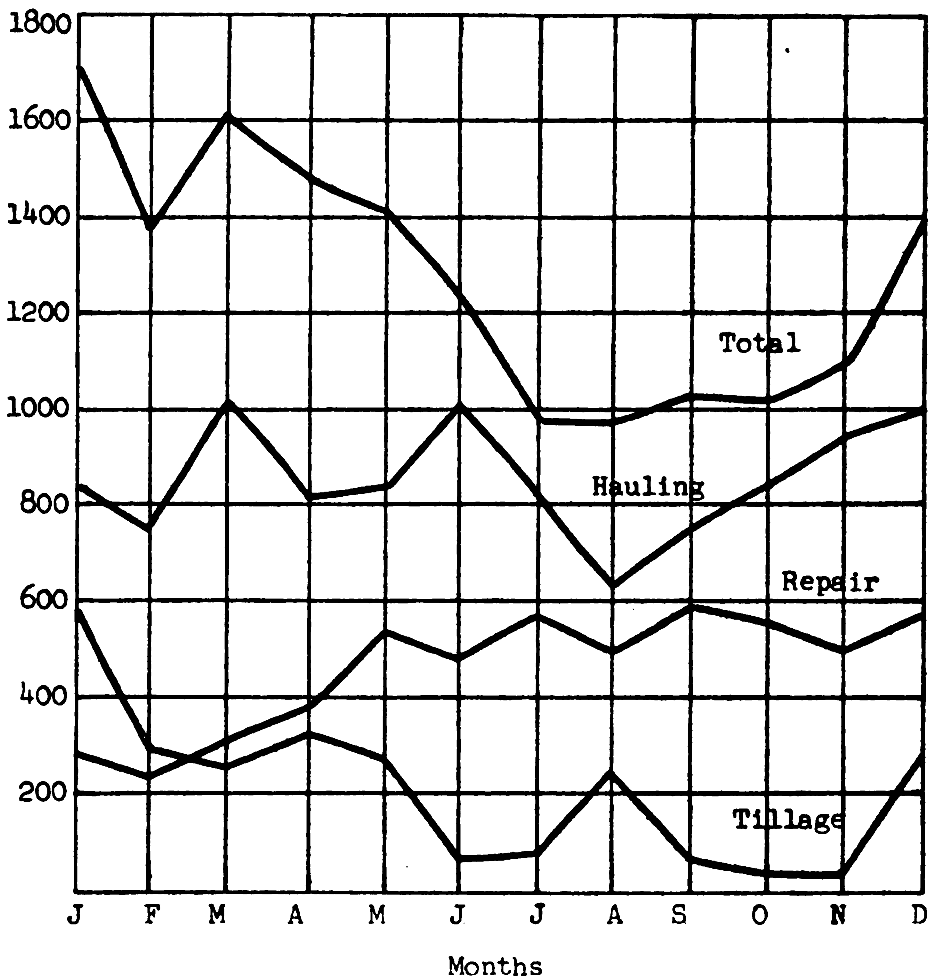


Figure 2.2 Total Tractor Days of Various Operations by Month, 1962-1967

high demand for tillage or for total work could have reduced time thus causing a negative correlation. Also, good management of doing repair work during periods of low demand could have increased the negative correlation. There is evidence then that the machine station was scheduling repairs during off work seasons, but that also some repair time cut into the work time of the tractors during peak demand periods.

There were three main sources of work for the machine station tractors, 1) the KTCCA organizations, 2) private persons and companies, and 3) the agricultural cooperative societies, as shown in Table 2.2.

Within KTCCA, the irrigation and water sections used the tractors the most, followed by the machine station and central store. These sections accounted for 77% of the days tractors were used by KTCCA organizations in 1968 and increased to 83% in 1969. Between 1968 and 1969 the irrigation and water section increased their use of the tractors by over 300 days which was a 75% increase. The tractor station and central store decreased their use of the tractors during this same time. The use of the tractors by the rest of the KTCCA organizations and the Academy remained about constant during these years. Most of the work done for the KTCCA organizations was hauling and winch operations with a small amount of the other operations. The Academy and all of the KTCCA organization accounted for 34% of the total work days for the tractors in 1968. This increased to 37% of the total work days in 1969.

Private persons and companies usually hired the tractors for hauling. In 1968 hauling made up 93% of the total work days for this group and 80% in 1969. All types of work done for private persons and companies increased between 1968 and 1969. It was 15% of the total work days in 1968 and 20% in 1969. The largest work increase was for cultivation. This increase was largely due to the hiring of the tractors by cooperative organizations from outside the Comilla Thana.

Table 2.2 Type of Tractor Work and Organization For Whom Performed

	Days of Work 1968	1969
ACADEMY AND KTCCA ORGANIZATIONS		
Irrigation and water section (Hauling and winch)	416	731
Machine station and central store (Hauling and winch)	172	119
Creamery and cold store (Hauling and winch)	61	53
Academy (All Operations)	35	40
Other KTCCA Organizations (All operations)	78	81
Subtotal	762	1024
PRIVATE PERSONS OR COMPANIES		
Private persons or companies (Hauling)	326	443
Private persons or companies (Cultivation and other)	23	115
Subtotal	349	558
AGRICULTURAL PRIMARY SOCIETIES		
Agricultural societies (Plow and disc harrow)	425	363
Agricultural societies (Rotary tiller)	420	540
Agricultural societies (Hauling)	209	207
Agricultural societies (Rice Hulling)	69	38
Subtotal	1123	1148
TOTAL	2234	2730

Tillage was the most important tractor operation performed for the agricultural primary societies. In 1968, it was 75% of all the work days for the primary societies and it increased to 79% in 1969. The type of tillage, however, changed significantly during these two years from the disc harrow to the rotary tiller. The use of the tractors for hauling remained almost constant at about 18 to 19% of the total work days in 1968. The total number of work days for the primary societies increased in 1969 but accounted for only 42% of the total work days for the tractors.

Tractors and the Time Required for Tillage

One of the values of the tractors has been to reduce the time required to perform the tillage operation. The days required for tillage for various varieties of rice, using either bullocks or a combination of tractors and bullocks is shown in Table 2.3. (Cost and Returns, 1965-1969, raw data) The maximum tractor time, .26 days/acre (.64 days/ha) was used on IRRI 8 crop land and the minimum tractor time, .18 days/acre (.50 day/ha) was used on land grown to the Boro variety of rice as shown in Table 2.3. The difference in time spent in tractor tillage resulted from IRRI 8 land on the average, being tilled more times than the crop land of other varieties of rice. The actual tractor tillage rate for one pass of the machine varied between only .15 days/acre (.41 days/ha) and .16 days/acre (.44 days/ha) for all varieties of rice.

The time required for the bullocks to complete the tillage operation, when tractors were used, varied from 4.65 days/acre (10.7 days/ha) to 5.79 days/acre (14.2 days/ha). The time required for land preparation,

Table 2.3 Time Required for Tillage Using Tractors and Bullocks or Only Bullocks

	Improved Rice				Nonimproved Rice			
	IRRI 8		Taipei		Shiatta		Boro	
	Trac. and bull.	Bull.	Trac. and bull.	Bull.	Trac. and bull.	Bull.	Trac. and bull.	Bull.
Tractor:*								
Days/acre	.26	--	.22	--	.21	--	.18	--
Days/ha	.68	--	.54	--	.52	--	.44	--
Avg. times tilled	1.63	--	1.45	--	1.33	--	1.20	--
Bullock:**								
Days/acre	4.65	11.00	5.79	13.05	4.76	11.45	5.31	12.19
Days/ha	10.70	27.00	14.20	32.20	11.70	28.00	13.05	30.00
Total:								
Days/acre	4.91	11.00	6.01	13.05	4.97	11.45	5.49	12.19
Days/ha	11.38	27.00	14.74	32.20	12.22	28.00	13.49	30.00

* Tractor days based on an eight hour work day.
** Bullock days based on a four hour work day.

when only bullocks were used, varied from 11.00 days/acre (27.0 days/ha) to 13.05 days/acre (32.20 days/ha). For all rice varieties the quantity of bullock labor required when tractors were used was fairly constant at between 42% and 44% of the quantity of bullock labor required when only bullocks were used for tillage. Tractors used in combination with bullocks reduced tillage by 6 to 7 days per acre (14.75 to 17.25 days/ha). Thus, the real advantage to the farmer in using the tractors was the more than 50% reduction in the time required for him to prepare his land for planting.

Costs of Tillage

The cost of tillage using either tractors and bullocks or only bullocks is given in Table 2.4 (Cost and Returns, 1965-1969, raw data).

Table 2.4 Costs when Either Tractors and Bullocks or only Bullocks are Used for Tillage

		Cost in Dollars or Rupees							
		Improved Rice				Nonimproved Rice			
		IRRI 8		Taipei		Shiatta		Boro	
		Trac. and bull.	Bull.	Trac. and bull.	Bull.	Trac. and bull.	Bull.	Trac. and bull.	Bull.
Tractor:*									
Cost/acre	$	5.65		4.58		4.45		4.27	
	Rs.	26.83		21.79		21.14		20.27	
Cost/ha	$	14.85		11.25		10.50		10.25	
Bullocks:**									
Cost/acre	$	3.18	8.05	3.58	7.93	2.84	7.05	3.48	7.20
	Rs.	15.11	38.15	17.02	37.66	13.50	33.54	16.52	34.30
Cost/ha	$	7.80	19.80	8.80	19.50	7.00	17.35	8.55	17.70
Human Labor:***									
Cost/acre	$	1.45	3.45	1.87	3.45	1.85	3.62	1.93	3.65
	Rs.	6.88	16.39	8.88	16.39	8.78	17.21	9.10	17.40
Cost/ha	$	3.56	8.50	4.60	8.50	4.55	8.90	4.75	9.00
Total:									
Cost/acre	$	10.28	11.50	10.03	11.38	9.14	10.67	9.68	10.85
	Rs.	48.62	54.54	47.69	54.05	43.42	50.75	44.77	51.70
Cost/ha	$	26.21	28.30	24.65	28.00	22.05	26.25	23.55	26.70

* Tractor cost, based on average amount actually paid by farmers

** Bullock cost, based on rental price for bullocks of $.63 (Rs.3.00) per bullocks pair for a 4 hour day.

*** Human labor cost, based on a wage rate of $.63 (Rs.3.00) for 8 hour day.

The amount paid by farmers for tractor tillage varied from $5.65 per acre ($14.00/ha) to $4.27 per acre ($10.50/ha). The cost per acre for one tractor tilling was, however, approximately constant for all rice varieties and averaged $3.40 per acre ($8.40/ha). The charge made to the village cooperative organizations by the machine station to till one acre of land one time was on the average $2.45 ($5.70/ha). Thus, the farmer's cost for tractor tillage was about 40% more than the tractor station charges for this same tillage, with the difference going to the cooperative societies. Whether this additional cost paid by the farmer to the cooperatives was a cost, necessary for the administration of the mechanization program through the cooperatives, or whether the cooperatives were simply making a profit from tractor mechanization is not known.

The bullock cost is based upon the amount a farmer would pay were he to hire the bullocks to do his tillage. These figures give no information as to the actual cost of owning and maintaining bullocks. In the Comilla Thana the average rental price is $.63 per bullock pair for a 4 hour day. Using this rental price, the cost for bullocks when both tractors and bullocks were used for tillage varied from $2.84/acre ($7.00/ha) to $3.58/acre ($8.85/ha) for the different rice varieties. When only bullocks were used for tillage their cost varied from $7.05/acre ($17.40/ha) to $8.05/acre ($20.00/ha). Thus, the cost of bullock labor is substantially less when they are used with tractors than when they are used as the only source of power for tillage.

The human labor cost is the amount paid for a person to operate a pair of bullocks. This cost is based upon a wage rate of $.63 for an eight hour day. The cost for a tractor driver is already included in the tractor rental cost so it is not included in the cost of human labor. The value of human labor when tractors and bullocks were used for tillage varied from $1.45/acre ($3.58/ha) to $1.93/acre ($9.00/ha).

Total cost for tillage is obtained by adding the tractor, bullock, and human labor costs. Total cost when tractors and bullocks were used for tillage varied from $9.14/acre ($20.50/ha) to $10.28/acre ($25.40/ha). Total cost when only bullocks were used varied from $10.67 to $11.50 per acre ($26.30 to $27.50/ha). On the average, the total cost when tractors and bullocks were both used was from 12% to 16% less than when only bullocks were used for tillage.

As was mentioned previously, these figures reflect the cost to the farmer if he were to either hire bullocks and a tractor to perform his tillage or to hire only bullocks to perform his tillage. These costs indicate that, at the prices that were charged, if a farmer needed to hire additional power for his tillage operation, hiring the tractors would be less expensive than hiring bullocks. Thus, farmers who had a shortage of power for tillage appear to have been justified in hiring tractors to supplement their bullocks. The tractor hire service did not operate at a profitable level during the first seven years. The introduction of tractors did, however, increase agricultural production and as was demonstrated in Chapter 1 was of benefit to the small farmers.

CHAPTER 3

3.0 INTRODUCTION

Based upon the discussion of Chapter 1 and Chapter 2 it appeared desirable to develop a method for evaluating and analyzing the various types of tractor hire services. Systems analysis including abstract modeling and computer simulation seemed to be an appropriate method for performing this analysis. Simulation modeling provides an effective means for incorporating a comprehensive analysis of the relevant factors and parameters which should be considered in developing any agricultural mechanization programs.

Models can be either static or dynamic in time. Dynamic models are more complex and difficult to construct, but they more nearly represent the real world. Since an accurate representation of actual tractor hire service operations was considered desirable for this study, a dynamic modeling approach was selected. One simulation technique which is applicable to a variety of situations is a simulation procedure whereby a model is developed which approaches a one to one correspondence of systems components with the real world (Fridley and Holtman, 1973). This approach appeared appropriate and was applied to the dynamic model developed in this study.

The objectives of the simulation modeling portion of the study were as follows:

1. Develop a generalized model for tractor hire service operation.
2. Develop a model for simulating demand for tillage by farmers in village level cooperatives.

3. Develop a model for simulating repair occurrence, duration, and cost for tractor breakdowns.

4. Using the models developed above, analyze tractor hire services and develop guidelines for their use in developing countries.

Development of the tractor hire service model is discussed in this chapter. The tillage demand model and the repair models are discussed in Chapters 4 and 5 respectively. Analysis and conclusions concerning tractor hire services using the model are discussed in Chapter 6.

3.1 GENERAL DESCRIPTION OF THE MODEL FOR TRACTOR HIRE SERVICE OPERATION

The model for tractor operation has been developed to represent, as closely as possible, the actual operation of tractor hire services. The model was developed to simulate cooperative, government, and individual owner contract hire services. Farmers in Bangladesh, Thailand, Malaysia, and several African countries have utilized tractor hire services almost exclusively for land preparation. (Esmay, 1972; Chancellor, 1970; Cervinka, 1969; Stout, 1971). Therefore, the model has been developed to simulate tractor hire service as it is applied to land preparation. Tractor powered land preparation in Asia has taken the form of both wet land and dry land tillage. In Bangladesh, Thailand, and Malaysia wet land tillage has usually been performed using a rotovator while dry land tillage has been performed using a disc harrow. Both wet and dry land tillage can occur during the same season under certain conditions. Therefore, the model contains a method for handling both types of tillage when they occur, either separately or simultaneously during a season. Harrow and rotary are the names used in the model to designate dry land and wet land tillage respectively. If analysis of tillage implements other than disc harrows or rotovators is desired, the model has as input data, appropriate machine parameters which can simulate the operation of most tillage tools.

In tropical agriculture there may be several cropping seasons each of which create a period of demand for tractor tillage. The model has been developed to handle up to four demand periods.

The tractors in most tractor hire services are contracted on a daily basis rather than an area basis. In Comilla, for example, tractors were hired for a minimum of 1/2 day with one day being the usual hiring period. For the model to provide an accurate simulation of tractor hire service operation a time increment of one day has been selected.

The model has been designed to simulate up to 15 years of tractor hire service operation. The number of times this sequence of years of tractor hire service operation can be simulated in one execution of the program is unlimited. A maximum of 25 tractors can be operated by the tractor hire service in the model. It is assumed in the model that all of the tractors are of approximately the same horsepower size and that they have similar operating speeds, breakdown characteristics, and field capacities.

3.2 IMPLEMENT ASSIGNMENT TO TRACTORS

The number of tractors (NTRT), harrows (HARMAX), and rotovators (ROTMAX) owned by the tractor hire service is read in as data by the program for each year of simulation. Before executing the first year of the simulation the program is initialized in the following manner.

Implement Assignment Initialization

First, the program assigns identification numbers from 1 through NTRT to each of the tractors. In a real tractor hire service, when tractors and equipment are initially delivered the tractor and equipment are usually in operating condition. Therefore, when the program initializes the simulation the assumption is made that the number of tractors available for work (NTRW) equals the total number of tractors (NTRT). The identification numbers of all of the tractors are initially stored in the array of identifying tractors available for work (ITRW). Since all of the tractors are available for work, the program sets the number of tractors under repair (NTRR) and the array for identifying tractors under repair (ITRR) equal to 0.

Next, the initial assignment of implements to the tractor is made. The program calculates the number of tractors equipped with rotovators (NTRROT) as the minimum of NTRT/2 or ROTMAX. The number of tractors equipped with harrows (NTRHAR) is then NTRT - NTRROT. Tractor 1 through NTRROT is sequentially assigned to rotovator 1 through NTRROT and tractor NTRROT + 1 through NTRT is sequentially assigned to harrow 1 through NTRHAR.

In a real tractor hire service a sufficient number of implements are purchased so that for each tractor there is at least one tillage tool. In the model this implies that the number of rotovators plus the number of harrows equal or exceed the number of tractors. When this sum exceeds the number of tractors then some implements must be idle. The number of idle harrows (NHARI) is equal to HARMAX - NTRHAR and the number of idle rotovators is equal to ROTMAX - NTRROT. The identification numbers of the idle harrows and rotovators are stored in arrays IHARI and IROTI respectively.

Implement Reassignment Due to Demand

Once implements are assigned to tractors only under special conditions will the implements be changed. One of these conditions occurs when demand for one type of tillage on a given day exceeds the number of tractors equipped with that type of tillage tool. For example, when demand for rotary tillage exceeds the number of tractors equipped with rotovators the program assigns idle rotovators to tractors until one of the following conditions occur, 1) the number of tractors with rotovators equals the demand for rotary tillage, 2) all of the rotovators have been assigned to tractors, or 3) the demand for harrow tillage equals the number of tractors equipped with harrows. Harrow tillage is handled using the same procedure.

The third condition mentioned above requires some additional clarification. When both types of tillage are demanded on the same day it is possible that the demand for each type of tillage could exceed the number of tractors equipped with that type of tillage tool. In this situation all of the tractors available for work are being utilized and, with but one exception, no implement changes are made on the tractors. The exception occurs when both of the following conditions are met, 1) both types of tillage exceed the number of tractors available for performing that tillage and 2) the delay in performing one type of tillage exceeds the delay in performing the other type of tillage. A basic assumption of the model is that tillage be performed in the order in which demand is received by the tractor hire service. This is not met as long as the delay in performing one type of tillage exceeds the delay in performing the other type of tillage. Therefore, the model must reassign implements to tractors when these delays are unequal. The following example illustrates how this is done in the model. If the delay in performing harrow tillage is three days while the delay in performing rotary tillage is four days then a harrow is replaced by a rotovator on one of the tractors. Replacement of additional harrows by rotovators take place on succeeding days of the simulation until the delays for both types of tillage are the same. A similar procedure is followed when replacing rotovators with harrows.

In a real tractor hire service when an implement is to be changed on one of several tractors and several implements are available for mounting no set procedure is used in selecting either the tractor on which the change is to be made or the implement to be mounted. In the model this procedure is simulated by selecting an implement at random from the array of idle implements and assigning it to a tractor selected at random from a list of tractors equipped with the other type of implement.

Implement Reassignment Due to Repair

A detailed discussion of tractor repair is given in Chapter 5. In discussing implement reassignment the definition of field breakdowns and major breakdowns is needed. In an actual machinery hire service, field breakdowns are breakdowns which occur during field operations, can be repaired without the tractor being taken to the repair facility, and usually require one day for repairs to be completed. The implement usually remains on the tractor during this repair. Major repairs are defined as those repairs which require the tractor to be taken to a repair facility and usually requires more than one day to repair. Often the implement is removed during the time required to repair a tractor following a major breakdown.

The model contains a procedure which simulates this behavior. When either type of breakdown occurs in the model the implement is assigned to the array of idle machines. For field breakdowns, however, the implement is placed in the array of idle machines in such a way that this machine is reassigned to the same tractor when the field repair is completed. When repairs resulting from major breakdowns are completed the model assigns the same type of implement to the tractor as it had prior to the breakdown as long as an idle implement of this type is available. However, no attempt is made to reassign the same implement to the tractor it had prior to the breakdown.

Implement Reassignment Due to Sale or Purchase of Tractors or Implements

The model allows the number of tractors and implements to be changed each year through purchase or sale. The model also provides for the replacement of tractors and implements at the end of any season. When the number of implements is reduced, the implements which have had the largest amount of use are sold first. If one of these implements is mounted on a tractor at the time of sale then this implement is replaced on the tractor by a randomly selected idle implement of the same type. If this implement is already idle then no change in implement assignment is made. When the number of implements is increased through purchase then the new implements are initially assigned to the array of idle implements. When an implement is replaced then the new implement is either assigned to the same tractor as the old implement or replaces the old implement in the array of idle machines.

When the number of tractors is reduced by sale the implement which was mounted on that tractor is placed in the array of idle machines. When the number of tractors is increased then a harrow is randomly selected and mounted on the tractor. If no harrows are idle then a rotovator is randomly selected and assigned to the tractor. When an old tractor is replaced the same implement assigned to the old tractor is reassigned to the new tractor.

3.3 TRACTOR AND IMPLEMENT ASSIGNMENT TO DEMAND

The process of determining the number of tractors equipped with each type of tillage implement was described in section 3.2. When this process is completed, tractors are assigned to demand. In the tractor hire service at Comilla, Bangladesh, tractors are hired either for a full day or a half day of tillage. Usually the demand for full days of tillage were assigned to tractors before assignments were made to half days of demand. Whenever possible two half days of demand were treated as a whole day of demand and assigned to one tractor. Any remaining half day of demand was then assigned to a tractor. All demand was assigned randomly to the tractors available for work. A similar procedure of assigning tractors to demand is used in the model.

In the model tractors are first assigned to full days of demand before they are assigned to half days of demand. When the number of tractors available to meet either type of demand on a given day exceeds the number required to meet this demand, then the order in which tractors are assigned is randomized before the tractors are assigned to the work. When the demand equals or exceeds the number of tractors available, then all of the tractors are used and randomization of the order in which tractors are assigned is not required.

3.4 DEMAND DELAY WITH ATTRITION

A delay in performing demand occurs in a tractor hire service when 1) demand for tillage exceeds the number of tractors available to perform this tillage and 2) a breakdown of a tractor and implement occur. A breakdown often requires that another tractor and implement complete the tillage work. In countries where communications are poor and tractors have to travel long distances (several miles) to the area being tilled, usually this tillage cannot be completed until the day following the breakdown.

Delays in performing demand, whatever the reason for the delay, can cause serious problems in the effective operation of a tractor hire service. Demand will almost always be reduced when tillage cannot be performed at the desired time. This reduction may result either from demand being withdrawn or from requests for tractor services not being made because of the long waiting list.

The model attempts to simulate the behavior described above. The length of time demand has been delayed is important in determining if demand will be withdrawn. Therefore the program keeps track of the number of days each request for tillage is delayed. The model does this by storing the demand which is delayed in an array. The index for each array element corresponds to the number of days the demand has been delayed. The number of requests which have been delayed for the given number of days is stored as the element of the array. Demand which is delayed because the demand exceeds the number of tractors available and demand which is delayed because of breakdowns are calculated and added together for each day of the simulation prior to this total being placed in the array. Each additional day that demand is delayed in the simulation, the program moves the delayed demand to the array element corresponding to the new number of days of delay. Since the model assigns tractors to the demand in the order in which the demand is received, tractors are assigned to perform the demand which has been in the delay the longest before being assigned to perform more recent tillage demand.

The loss of demand is included in the model in the form of attrition from the delay process. The model assumes that loss of demand does not occur until after at least two days of delay and that all demand which exceeds 12 days of delay is lost. Within these two limits, an attrition rate expressed as a proportion of the demand lost for each day of delay is required by the model. These attrition rates can be varied to test the model's sensitivity to various rates of demand withdrawal. A discussion concerning the effect of demand withdrawal is included in Chapter 6.

3.5 TILLAGE CAPACITY OF TRACTORS AND IMPLEMENTS

The operating capacity, amount of tillage which can be performed by a tractor and implement per day, is dependent upon the time efficiency and field efficiency of a machine. Hunt has described the factors which should be considered to determine time efficiency (Hunt, 1964). Applied to a tractor hire service, the time elements which should be included when computing the capacities of equipment are:

1. Tractor and equipment preparation time prior to leaving the location of the tractor hire service.
2. Travel time to and from the area of work.
3. Machine preparation time in the field both prior to and following the field operation.
4. Theoretical field time (the time the machine is operating in the field at an optimum forward speed and performing over its full width of action).

5. Turning time and time to move from one field to the next.

6. Machine adjustment time.

7. Field maintenance time (lubrication, refueling, etc -- does not include daily servicing)

8. Operator personal time (lunch break or other rest periods during the day provided for the operator)

Field efficiency is defined as the ratio of the theoretical field efficiency, element 4 of the above list, to the total time spent in the field. Factors which affect field efficiency include:

1. Pattern of the field operation

2. Shape of the field

3. Size of the field

4. Theoretical capacity of the machine

Implementation in the Model

As mentioned above, the pattern, shape, and size of the fields are important in determining the field efficiency of a machine. Field plot sizes in many developing countries are small. In the Comilla Thana field plots averaged only .30 acres (.12 ha). Generally the plots are fairly regular in shape with many of them rectangular or square. For purposes of the model square fields were assumed. Field width therefore equals field length and can be determined using equation 3.5.1.

$$WIDTHFD = (43{,}560 * PLOTSIZ)^{.5} \qquad 3.5.1$$

where WIDTHFD = Width of the field in feet

PLOTSIZ = Size of the plot in acres

Plot size is included in the model as an input variable, thus allowing an analysis of the effect of plot size on tractor operation.

The theoretical field time is calculated using equation 3.5.2.

$$TILTIM_i = \frac{WIDTHFD * TURNNUM_i}{TILSPD_i * 5280} \qquad 3.5.2$$

where i = Type of implement being used for tillage

$TILTIM_i$ = Theoretical time to till the field, hrs.

$TURNNUM_i$ = Number of passes required to till the field also equals the number of turns made at the end of the field

$TILSPD_i$ = Till speed in mi/hr

The number of passes required by the machine to till the field ($TURNNUM_i$) is calculated with equation 3.5.3.

$$TURNNUM_i = WIDTHFD/EFFIMWD_i \qquad 3.5.3$$

where $EFFIMWD_i$ = Effective implement width

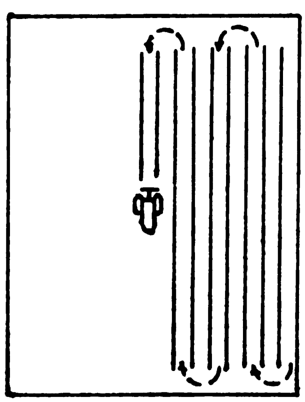
The effective implement width is less than the actual implement width since some overlap of the machine on previously tilled ground is usually unavoidable. The effective implement width is calculated using equation 3.5.4.

$$EFFIMWD_i = WIDTHIM_i * (1 - TILOVLP) \quad 3.5.4$$

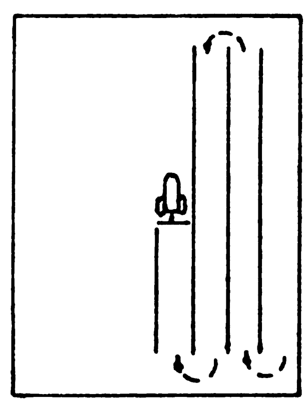
where $WIDTHIM_i$ = Width of the implement i, ft.

TILOVLP = Amount of machine overlap expressed as a proportion of the total machine width

Two types of turns appear appropriate for tillage tools. The first, illustrated in Figure 3.1A is the straight alternation pattern and is used when the width of the implement is less than or equal to the width of the tractor (WIDTHTR).



3.1A



3.1B

Figure 3.1 Patterns for Tilling Fields

The second method is the continuous pattern illustrated in Figure 3.1B and is used when the implement is wider than the tractor. The turning radius (TURNRAD) for the straight alternation pattern is given by equation 3.5.5 and the turning radius for the continuous pattern is given by equation 3.5.6.

$$TURNRAD_i = EFFIMWD_i \qquad 3.5.5$$

$$TURNRAD_i = EFFIMWD_i/2 \qquad 3.5.6$$

The time in hours spent in turning ($TURNTIM_i$) while tilling the field is given by equation 3.5.7.

$$TURNTIM_i = \frac{\pi * TURNRAD_i * TURNNUM_i}{TURNSPD_i * 5280} \qquad 3.5.7$$

where $TURNTIM_i$ = Turning time for implement i, hrs.

$TURNSPD_i$ = Turning speed, mph.

$TURNNUM_i$ = Number of turns calculated by equation 3.5.3

The capacity of the tillage implement in acres/day, assuming two passes of the equipment over the field constitutes tilling the field one time, is given by equation 3.5.8.

$$CAP_i = \frac{PLOTSIZ * (WORKHRS - TIMIDLE)}{2 * (TILTIM_i + TURNTIM_i)} \qquad 3.5.8$$

where CAP_i = Implement tillage capacity, acres/day

WORKHRS = Length of the work day, hrs.

TIMIDLE = All the time during the day when the tractor is not working in the field. This includes equipment preparation time, travel time, field maintenance time, and the operator personal time

The fuel cost can be calculated using equation 3.5.9 once field capacity (CAP_i) is known.

$$FUELCT_i = CAP_i * FUEL_i * FUELPRC \qquad 3.5.9$$

where $FUELCT_i$ = Fuel cost for implement i, money units/day

$FUEL_i$ = Fuel consumption, gal/acre

$FUELPRC$ = Purchase price of the fuel, money units/gal

The 1970 prices and values for the variable used to calculate capacity are shown in Table B.11 of Appendix B. These values are used as the normal operating values in the model. The model, however, provides the opportunity to vary the initial values and determine tractor hire service operation sensitivity to these changes. The model also provides for a yearly inflation rate in the price of purchased products, such as fuel. This rate can then be altered to test the long range effects of inflation on tractor hire service operation.

3.6 TRACTOR HIRE SERVICE COST DETERMINATION

Machinery costs are divided into two categories, fixed costs and variable costs. Variable costs are those which increase proportionally with the amount of operational use given the machine. The fixed costs are independent of use. Which category of use some of the specific costs belong in is not always clear. The cost of interest on the machinery investment, taxes, housing, and insurance are dependent upon calendar-year time and are clearly independent of use. Cost of fuel and lubrication are clearly costs associated with use. Depending upon the type of tractor hire service, the cost of labor may be either a fixed cost or a variable cost. The two remaining cost items, depreciation and repair costs are often functions of both use and time. In the model both repair costs and depreciation are assumed to be functions of use. The fixed cost, variable cost, and labor cost are determined for each tractor in the model and then added together to get a total cost of operation. Costs of tractor hire service operation are calculated for each tractor in the model on a seasonal, yearly, and life time basis.

Fixed Cost

Fixed costs in the model are those costs which do not change during a year. The model determines a yearly interest and insurance cost on the tractor and machinery investment using the present value of each tractor and implement at the beginning of the year. The present value of each tractor and implement at the beginning of a year is calculated as the value of the tractor or implement at the beginning of the previous year less its depreciation during the year as shown in equation 3.6.1.

$$VAL_t = VAL_{t-1} - DEP_{t-1} \qquad 3.6.1$$

where t = Time in year

VAL = Present value of tractor or implement

DEP = Depreciation of tractor or implement

At the beginning of the first year no depreciation has yet taken place and the present value is equal to the initial price (INTPRC), VAL_1 = INTPRC.

All costs in the model are distributed on a per tractor basis. Therefore, the yearly interest and insurance cost of the harrows and rotovators are prorated to each tractor. The yearly fixed cost per tractor (YRTRFC) excluding fixed labor costs, is then given by equation 3.6.2.

$$YRTRFC_i = (TRVAL_i + ((\sum_{j=1}^{HARMAX} HVAL_j + \sum_{k=1}^{ROTMAX} RVAL_k)/NTRT)) * (INT + INSUR) + STO \qquad 3.6.2$$

where YRTRFC = Yearly fixed cost for tractor i

TRVAL = Present value of tractor i

HVAL = Present value of harrow j

RVAL = Present value of rotovator k

HARMAX = Number of harrows owned by the tractor hire service

ROTMAX = Number of rotovators owned by the tractor hire service

NTRT = Number of tractors owned by the tractor hire service

INT = Yearly interest rate

INSUR = Yearly insurance rate

STO = Yearly shelter and storage costs per tractor

Since fixed costs including fixed labor costs are desired in the model on a seasonal basis, the yearly fixed cost is prorated to each season on the basis of the number of calendar days in the season as shown in equation 3.6.3.

$$TRFC_{ij} = YRTRFC_i * NDAY_j/365 + TRLBCTF_{ij} \qquad 3.6.3$$

where $TRFC$ = Fixed cost for tractor i during season j

$YRTRFC$ = Yearly fixed cost for tractor i

$NDAY$ = Number of days in season j

$TRLBCTF_{ij}$ = Fixed tractor labor cost for tractor i in season j as calculated in equation 3.6.14

Variable Costs

Variable costs in the model, those which increase proportionally with use, include fuel and depreciation and part of the labor cost. Fuel cost per day of tractor operation for each type of tillage tool has been calculated in section 3.5. To determine the seasonal or yearly cost for each tractor only requires that the days of each type of tillage performed by the tractor during the season or year be multiplied by the fuel cost per day for that type of tillage.

The straight line method of depreciation has been chosen for the model. This method seems justified since in most developing countries, machine value seems to decrease fairly constantly over the life of the machine. There does not seem to be a fast drop in machine value during the first few years of machine life as is experienced in developed countries. Equation 3.6.4 is used by the model to calculate depreciation.

$$DEP_i = \frac{INTPRC - SALVAL}{LIFE} \qquad 3.6.4$$

where DEP_i = Depreciation of tractor or implement i, money units/day of life

$INTPRC$ = Initial price of tractor or implement where SALVAL = Salvage value of tractor or implement, money units

LIFE = Tractor or implement life, days of operation

Since depreciation given in equation 3.6.4 is expressed as depreciation per day of operation, depreciation per season or year is calculated by multiplying the days of operation of each implement and tractor by the daily depreciation rate. As with interest and insurance costs of the implements, the depreciation cost of implements are included in the operating cost of each tractor. Variable cost for each tractor is then given by equation 3.6.5.

$$VARCOST_{ij} = TRDEP_i * (DAYH_{ij} + DAYR_{ij}) + HARDEP * DAYH_{ij} + ROTDEP * DAYR_{ih} + FUELCTH * DAYH_{ij} + FUELCTR * DAYR_{ij} + TRLBCTV_{ij} + TRRPCT_{ij} \qquad 3.6.5$$

where $VARCOST_{ij}$ = Variable cost for tractor i in season j, money units

$TRDEP_i$ = Depreciation of tractor i, money units/day of operation

HARDEP = Harrow depreciation calculated using equation 3.6.6

ROTDEP = Rotary depreciation calculated using equation 3.6.7

$DAYH_{ij}$ = Days of harrow tillage performed by tractor i in season j

$DAYR_{ij}$ = Days of rotary tillage performed by tractor i in season j

FUELCTH = Fuel cost for harrowing, money units/day

FUELCTR = Fuel cost for rotary tillage, money units/day where $TRLBCTV_{ij}$ = Variable tractor labor cost for tractor i in season j as calculated in equation 3.6.15

$TRRPCT_{ij}$ = Repair cost of tractor i in season j, calculated as described in Chapter 5

The depreciation per day of operation for the harrows and rotovators may vary since depreciation is based upon initial price and machines purchased at different times may have different prices. The harrow (HARDEP) and rotovator (ROTDEP) depreciation per day of operation for a season or year is therefore calculated using equations 3.6.6 and 3.6.7 respectively.

$$HARDEP = \frac{\sum_{i=1}^{HARMAX} (HDEP_i * HDAY_i)}{\sum_{i=1}^{HARMAX} HDAY_i} \quad 3.6.6$$

$$ROTDEP = \frac{\sum_{i=1}^{ROTMAX} (RDEP_i * RDAY_i)}{\sum_{i=1}^{ROTMAX} RDAY_i} \quad 3.6.7$$

where HARXAM = Number of harrows owned by the tractor hire service

ROTMAX = Number of rotovators owned by the tractor hire service

$HDEP_i$ = Depreciation of harrow i, money units/day

$RDEP_i$ = Depreciation of rotovator i, money units/day

$HDAY_i$ = Days of tillage performed by harrow i

$RDAY_i$ = Days of tillage performed by rotovator i

Labor Costs

Labor costs can be either fixed, variable, or a combination of the two depending upon the type of tractor hire service. Individual contract hire services usually have labor costs which are proportional to tractor use. Tractor drivers with this type of tractor hire service are paid a part of the income the tractor earns. Tractor drivers are not paid during periods when the tractor is idle. This is usually not the case with either government or cooperative tractor hire services. Usually with these types of tractor hire services, personnel are hired on a year round basis and paid a salary whether or not work is performed. Tractor drivers may also be paid a field allowance when work is actually performed.

In the Comilla Thana, tractor hire service personnel included a manager, a superintendent, tractor drivers, and mechanics. All of whom were on a fixed salary. The tractor drivers and mechanics received a base salary, a housing allowance, and a medical allowance. There was also a yearly increase in the salary. In addition, tractor drivers received a field allowance when the tractors were actually used for tillage. The cooperative tractor hire service also paid a commission to the cooperative manager of the primary farmer cooperatives for each day of tillage performed for his cooperative. The commission was to compensate the cooperative manager for arranging to have the tractors work for his cooperative and collecting the fee from the farmers whose land was tilled.

In the model, the basic monthly salary for tractor drivers and mechanics for each year is shown in equation 3.6.8.

$$SALMO_t = SALMO_{t-1} + YRINC \qquad 3.6.8$$

where t = Time in years

SALMO = Basic salary for tractor drivers and mechanics, money units/mo

YRINC = Yearly increase in the monthly wage, money units/mo

The basic salary for the tractor hire service manager and superintendent also increased each year and is calculated using equations 3.6.9 and 3.6.10.

$$SALMGR_t = SALMGR_{t-1} *(1 + WAGEIFL) \qquad 3.6.9$$

$$SALSUP_t = SALSUP_{t-1} * (1 + WAGEIFL) \qquad 3.6.10$$

where t = Time in years

SALMGR = Salary of the manager, money units/year

SALSUP = Salary of the superintendent, money units/year

WAGEIFL = Wage inflation, proportion/year

Using the basic monthly salary (SALMO) from equation 3.6.8, the yearly salary for tractor drivers (DRVSAL) and mechanics (MCHSAL) is calculated using equations 3.6.11 and 3.6.12 respectively.

$$DRVSAL = SALMO * (12 + ALOWMD + ALOWHS) \qquad 3.6.11$$

$$MCHSAL = SALMO * (12 + ALOWMD + ALOWHS) \qquad 3.6.12$$

where ALOWMD = Medical allowance, proportion of monthly salary

ALOWHS = Housing allowance, proportion of monthly salary

The yearly fixed labor cost (LABORFC) for a tractor hire service is then calculated using equation 3.6.13.

$$LABORFC = DRVSAL * TRDRV * NTRT + MCHSAL * TRMCH * NTRT + SALSUP + SALMGR \quad 3.6.13$$

where TRDRV = Number of tractor drivers for each tractor

TRMCH = Number of mechanics per tractor

NTRT = Number of tractors in the tractor hire service

Since labor costs in the model are desired on a seasonal basis for individual tractors, the yearly fixed labor cost is prorated for each season on the basis of the number of days in the season and then equally assigned to each tractor. The fixed and variable seasonal labor cost for individual tractors is given by equations 3.6.14 and 3.6.15 respectively.

$$TRLBCTF_{ij} = \frac{(LABORFC * NDAY_j/365)}{NTRT} \quad 3.6.14$$

$$TRLBCTV_{ij} = (COMM + ALOWFLD) * (DAYH_{ij} + DAYR_{ij}) \quad 3.6.15$$

where $TRLBCTF_{ij}$ = Fixed tractor labor cost for tractor i in season j

$TRLBCTV_{ij}$ = Variable tractor labor cost for tractor i in season j

LABORFC = Labor fixed cost from equation 3.6.13

$NDAY_j$ = Number of calendar days in season j

COMM = Cooperative manager's commission/day where $ALOWFLD$ = Field allowance for tractor drivers/day

$DAYH_{ij}$ = Days of harrow tillage by tractor i in season j

$DAYR_{ij}$ = Days of rotary tillage by tractor i in season j

$NTRT$ = Number of tractors owned by the tractor hire service

In the individual contract hire service, labor fixed cost (LABORFC) and commission (COMM) are set equal to zero and the field allowance (ALOWFLD) is increased to equal the total driver's salary for each day of the tractor's operation.

Total Cost

Total cost for each tractor each season is given as the sum of the seasonal fixed cost and variable cost as shown in equation 3.6.16.

$$TRCOST_{ij} = TRFC_{ij} + VARCOST_{ij} \qquad 3.6.16$$

where $TRCOST_{ij}$ = Total cost for tractor i during season j

$TRFC_{ij}$ = Fixed cost for tractor i during season j

$VARCOST_{ij}$ = Variable cost for tractor i during season j

The values from the Comilla tractor hire service which have been used as normal values when operating the model are shown in Table B.12 of Appendix B. The model allows these values to be altered to test the sensitivity of the tractor hire service to changes in the values.

3.7 TRACTOR AND EQUIPMENT REPLACEMENT, PURCHASE, AND SALE

All tractor hire services replace worn out or obsolete tractors and equipment. They also may at times alter the number of tractors and equipment which are in the tractor hire service. For this reason the model provides a method for replacing tractors and implements and for reducing or adding tractors and implements to the tractor hire service.

Tractor and Implement Replacement

The time for replacement has been studied extensively (Hunt, 1964). One method of establishing the time of replacement is to determine when the cost per unit of use has reached its lowest value. Whether a particular machine has a lowest cost point or not depends primarily on the type of variable costs associated with that machine. In the first type, variable cost is directly related to use. Many tillage tools have variable costs which are related directly to the amount of use. In this case the lowest cost per unit of work is attained by replacing the equipment at the end of its useful life. In the model the above procedure is implemented by replacing the disc harrows and rotovators when the accumulated days of operation of each implement exceeds the assumed life of the machine. This is the same point at which the present value of the implement is equal to or less than the salvage value.

The second type of variable cost is one in which variable costs are not directly proportional to use but instead increases with use. Tractors have this type of variable cost. With this type of variable cost, accumulated costs per unit of operation reach a minimum point sometime during machine life and increases thereafter. The time for replacement should then be at the point of least accumulated cost per unit of operation. However, this point is difficult or impossible to accurately determine. In the model an initial replacement time is chosen and the program is executed. The least accumulated cost per unit of operation and the time when it occurred is included as output. The replacement time can then be adjusted so that it equals the optimum time for tractor replacement.

In the model when either a tractor or implement is replaced, the total number of tractors or implements is not changed. The program simply assigns the identification number of the old tractor or implement to the new one and initializes the variables associated with it. The replacement of equipment is delayed an appropriate length of time to simulate the actual delay expected when importing equipment.

Tractor and Implement Purchase

In actual tractor hire services the demand for tractor service often increases with time. This may require that the number of tractors and implements increase in order to provide an effective service. The model therefore provides for increasing the number of tractors and implements in the tractor hire service. Tractor and implement increases in the model are allowed only at the beginning of each year. This assumes that the delays in importing and delivering equipment were compensated for by ordering the new tractor and implement well in advance of the beginning of each year when equipment numbers are to be increased. The model provides for the initial price of new equipment to be increased each year by an inflation factor. Thus, the effect of inflation can be determined in relation to the cost of operation of a tractor hire service. The new equipment is assigned to demand as described in sections 3.2 and 3.3.

Tractor and Implement Sale

Occasions arise in actual tractor hire services when demand for services decreases, either as a result of changing cropping patterns or expansion of private ownership. It therefore appeared desirable that the model provide a method for sale of tractors and implements to compensate for decreased demand. It is assumed in the model that tractors and implement numbers would be reduced only at the beginning of a year.

In actual practice, usually the piece of equipment which has had the largest amount of use is sold first. Therefore, the model selects for sale the machine which has the largest accumulated days of use. When sales take place the total number of tractors or implements of the type sold is decreased. Identification numbers of machines which are larger than the new total number of that type of machine are no longer appropriate. These machines are therefore given the identification numbers of the machines being sold.

It is assumed in the model that the tractors and implements are sold for their present value. If tractor numbers are decreased, this also decreases the number of tractor drivers and mechanics in the tractor hire service. Table B.12 includes the normal operating values for import delays, inflation rates, etc. required by the part of the model described in this section. This completes the description of the model for simulating tractor hire service operation.

CHAPTER 4

4.0 INTRODUCTION

Since the computer model simulates daily operation of a tractor hire service it is necessary for the demand portion of the model to predict tillage demand on a daily basis. Demand is country and regionally specific. For purposes of this study, demand for tractor tillage as experienced in the Comilla Thana of Bangladesh has been chosen for simulation. It is hoped, however, that the simulation techniques applied to demand for tillage in Bangladesh can, with minor modifications, be applied to other developing countries. The demand model consists of a deterministic model which predicts seasonal demand for tillage and an allocative model which distributes demand for tillage on a daily basis throughout each season.

4.1 DETERMINISTIC DEMAND MODEL

Demand for tillage in the Comilla Thana, Bangladesh, occured during four major periods each year. The first demand period preceded planting of the Boro season rice crop. The second preceded planting of the Aus season rice crop. The third and fourth demand periods preceded the planting of the early and late Amon season rice crops. The early and late Amon season rice crops are referred to in the model as Amon 1 and Amon 2 demand periods respectively.

The structural approach to systems modeling was the method chosen to develop the deterministic model of seasonal demand for tractor tillage.

This method is based upon an examination of system structure to determine basic system components and their interconnections. Characteristics of these system components and the constraints imposed by their interconnections are used to develop the overall model when using the structural approach. (Manetsch, 1972)

Analysis of cooperative structure for introducing agricultural development in the Comilla Thana indicated that basic components in developing a tractor demand model were 1)the number of irrigation and non-irrigation cooperatives, 2) the adoption and use of improved rice varieties, 3) the utilization of mechanical tillage for land preparation, and 4) various other characteristics of primary farmer cooperatives and their members. The rest of this section clarifies these components and their interactions in determining seasonal demand.

Seasonal Demand Prediction

Seasonal demand prediction has been made in the model using the equation 4.1.1.

$$DMD_k = \sum_{i=1}^{2} \sum_{j=1}^{2} T_{jk} * R_{ik} * M_{ijk} * S_{ik} \qquad 4.1.1$$

k = 1, Boro demand period
2, Aus demand period
3, Amon 1 demand period
4, Amon 2 demand period

where DMD_k = Demand in tractor days

T_{1k} = Irrigation cooperative rice acreage, acres

T_{2k} = Non-irrigation cooperative rice acreage, acres where R_{1k} = Proportion of cooperative rice acreage in improved rice varieties

R_{2k} = Proportion of cooperative rice acreage in non-improved rice varieties

M_{11k} = Proportion of irrigation coop improved rice acreage on which tractors are used

M_{12k} = Proportion of non-irrigation coop improved rice acreage on which tractors are used

M_{21k} = Proportion of irrigation coop non-improved rice acreage on which tractors are used

M_{22k} = Proportion of non-irrigation coop non-improved rice acreage on which tractors are used

S_{1k} = Rate of tractor tillage on improved rice land, days/acre

S_{2k} = Rate of tractor tillage on non-improved rice land, days/acre

The procedure used to calculate rice acreage (T_{ik}) varies for each season. Therefore, the determination of demand for tractor tillage each season is considered separately.

Boro Demand Period

The need for irrigation to grow crops during the Boro season was discussed in Chapter 1. Demand for tractor hire services varies between irrigation cooperatives, those with mechanical irrigation facilities in the form of deep tube wells or surface water pumps, and non-irrigation cooperatives, those dependent upon manual methods of irrigation. Both rice and non-rice crops are grown during the Boro season. Demand for tractor tillage, however, has generally been limited to rice land.

The equation 4.1.2 is used in the model to determine cooperative rice acreage in the Boro season.

$$T_{j1} = n_j * A_{1j} * C_{1j} \qquad j = 1, 2 \qquad 4.1.2$$

where T_{11} = Irrigation cooperative rice acreage, acres

T_{21} = Non-irrigation cooperative rice acreage, acres

A_{11} = Average Boro crop acreage per irrigation cooperative

A_{12} = Average Boro crop acreage per nonirrigation cooperative

n_1 = Number of irrigation cooperatives

n_2 = Number of non-irrigation cooperatives

C_{11} = Proportion of irrigation cooperative Boro crop acreage on which rice is grown

C_{12} = Proportion of non-irrigation cooperative Boro crop acreage on which rice is grown

Demand for tractor services during the Boro season (DMD_1) is determined by substituting T_{11} and T_{21} calculated in equation 4.1.2 into equation 4.1.1. Both harrow tillage and rotary tillage have been demanded during the Boro season. Since irrigation cooperatives have had more water for irrigation than non-irrigation cooperatives, they have demanded more wetland rotary tillage. In the model the demand for rotary tillage is expressed by equation 4.1.3.

$$DMR_1 = DMD_1 * n_1/(n_1 + n_2) \qquad 4.1.3$$

where DMR_1 = Demand for rotary tillage in tractor days where DMD_1 = Total demand for tractor tillage in the Boro season calculated from equation 4.1.1

n_1 = Number of irrigation cooperatives

n_2 = Number of non-irrigation cooperatives

The demand for harrow tillage (DMH_1) during the Boro season is then calculated as total demand (DMD_1) less rotary demand (DMR_1).

Aus Demand Period

Aus season provides the second period of tillage demand. Tillage for Aus rice occurs near the end of the dry season. Therefore, all of the tillage for this season takes place on dry land using disc harrows. The demand equation 4.1.1 which is used for the Boro season, is also applicable for the Aus season. However, the cooperative rice acreage for the Aus season (T_{j2}), is calculated differently.

The Boro season rice crop has not yet been harvested when the Aus rice must be planted. The acreage available for Aus rice is therefore determined as the annual crop land available for rice production in the irrigation and non-irrigation cooperatives less the acreage planted to Boro rice by each type of cooperative. Both the annual crop acreage and the proportion of crop acreage planted to rice is assumed to be the same for irrigation and non-irrigation cooperatives. Equation 4.1.4 is used in the model to determine cooperative rice acreage in the Aus season.

$$T_{j2} = (APC * C_2 * n_j) - (n_j * A_{1j}) \qquad 4.1.4$$

where T_{12} = Irrigation cooperative rice acreage, acres

T_{22} = Non-irrigation cooperative rice acreage, acres

A_{11} = Average Boro crop acreage per irrigation cooperative

A_{12} = Average Boro crop acreage per non-irrigation cooperative

APC = Average crop acreage per cooperative

C_2 = Proportion of cooperative Aus acreage on which rice is grown

n_1 = Number of irrigation cooperatives

n_2 = Number of non-irrigation cooperatives

The average crop acreage per cooperative (APC) is calculated using equation 4.1.5.

$$APC = APM * MPC \qquad 4.1.5$$

where APM = Acreage per cooperative member, acres

MPC = Average number of members per cooperative

Demand for the Aus season (DMD_2) is obtained by using the values of T_{12} and T_{22} calculated in equation 4.1.4 in equation 4.1.1.

<u>Amon Demand Periods</u>

Amon season demand for tillage comes at two separate times. The Amon 1 demand period follows the harvesting of the Boro rice crop. The Amon 2 demand period follows the harvesting of the Aus rice crop. More of the irrigation cooperative land is planted to Boro rice than is non-irrigation cooperative land. Thus, a larger proportion of irrigation cooperative land is planted to the early Amon season rice crop. More non-irrigation rice land is planted to Aus rice. Thus, a larger proportion of non-irrigation rice land is planted to the late season Amon rice.

The equations used in the model to determine cooperative rice acreage in the early Amon season (Amon 1) and the late Amon season (Amon 2) are given in equations 4.1.6 and 4.1.7 respectively.

$$T_{j3} = n_j * APC * P_j \qquad 4.1.6$$

$$T_{j4} = n_j * APC * (1-P_j) \qquad 4.1.7$$

where

T_{13} = Irrigation cooperative rice acreage for Amon 1 season

T_{23} = Non-irrigation cooperative rice acreage for Amon 1 season

T_{14} = Irrigation cooperative rice acreage for Amon 2 season

T_{24} = Non-irrigation cooperative rice acreage for Amon 2 season

APC = Average acreage per cooperative

P_1 = Proportion of irrigation cooperative rice acreage considered for Amon 1 demand

P_2 = Proportion of non-irrigation cooperative rice acreage considered for Amon 1 demand

n_1 = Number of irrigation cooperatives

n_2 = Number of non-irrigation cooperatives

Demand for the Amon 1 season is obtained by substituting the irrigation and non-irrigation acreage values, T_{13} and T_{23}, calculated in equation 4.1.6, into equation 4.1.1. Similarly demand for the Amon 2 season is obtained by substituting the acreage values, T_{14} and T_{24}, calculated in equation 4.1.7, into equation 4.1.1.

4.2 VALIDATION OF THE DETERMINISTIC DEMAND MODEL

Before applying the deterministic demand model developed in section 4.1 to the model for tractor hire service, it is necessary to show that the model is a valid predictor of actual demand for tractor hire services. The demand experiences of the tractor hire service in the Comilla Thana, Bangladesh, is used to test the validity of the model. Since the model describes an existing system, validation involves demonstrating that the model exhibits behavior characteristic of the system itself. This is done by attempting to reproduce past demand for tractor hire services. One of the important variable parameters included in the model is the use of improved varieties. In the Comilla Thana the adoption of improved varieties by farmers during the Boro season went from 0% to 86% between 1966 and 1969. During this same time period, the tractor hire service in Comilla seemed to have a sufficient number of tractors to meet all demand for tractor tillage coming from the primary farmer cooperative organizations in the thana. Thus, tractor operation during these years, as recorded by the tractor hire service, seemed to accurately reflect the total demand for tractor tillage and demand losses due to delay in performing tillage was assumed to be zero. For the preceding reasons, demand in the 1966-1969 time period was chosen to validate the model.

In testing the validity of a model developed using the structural approach, values for the input variables and parameters of the model must be determined independently from the output of the real system. This condition was met for the tractor demand model by determining values for the input variables and parameters using farmer surveys and research reports of the Academy for Rural Development located at Comilla. A list of the values of the input variables and parameters used to test the validity of the model, including the source of these values, is given in Table B.1 and B.2 of Appendix B.

The actual demand for tractor hire services based upon tractor use and seasonal demand as predicted by the model for the years 1966-1969 is shown in Table 4.1. Since there is only one value for both the actual and predicted demand for each demand period in each year a rigorous statistical analysis is impossible. However, the difference between the actual and predicted days of tillage demand and the percent error expressed as the actual minus the predicted demand divided by the actual demand does give some indication as to the validity of the model.

The difference between the actual and the predicted days of tillage demand for each season is shown in Table 4.1. The difference varied from a maximum of 29.9 days for harrow tillage in the Aus season of 1967 to a minimum of 1 day for rotary tillage in the Amon 1 season of 1966. The difference between the actual and predicted demand was 15 days or less in

Table 4.1 Days of Actual Demand for Tractor Tillage and Demand Predicted By the Deterministic Demand Model

	1966				1967				1968				1969			
	Act-ual	Pre-dict	Dif	% Error	Act-ual	Pre-dict	Dif	% Error	Act-ual	Pre-dict	Dif	% Error	Act-ual	Pre-dict	Dif	% Error
Boro																
Harrow	74	59.6	14.4	19.5%	106.5	101.5	5	4.7%	174	151.9	22.1	13.8%	159	167.8	8.8	5.5%
Rotary	4.5	13.4	8.9	197%	53	39.5	13.5	25.5%	153.5	146.1	7.4	4.8%	290	299.8	9.8	3.4%
Aus																
Harrow	78	84.1	6.1	7.8%	112	141.9	29.9	26%	227.5	200.6	26.9	11.8%	160.5	163.3	2.8	1.7%
Amon 1																
Rotary	34	33	1	2.9%	60	63.3	3.3	5.5%	103	114.4	11.4	11%	156.5	165.8	9.3	6%
Amon 2																
Rotary	65	49.9	15.1	23%	89.5	74.4	15.1	16.9%	91.5	94.8	3.3	3.6%	112	116.2	4.2	3.7%
Mean			9.1				13.36				14.22				6.98	
Std dev			5.88				10.57				9.96				3.23	

85% of all demand periods. The difference for each season was used to calculate a yearly mean and standard deviation. Table 4.1 indicates that the mean of the difference varied from 6.98 days in 1969 to 14.22 days in 1968. A statistical analysis, however, indicated that these means were not significantly different at the .1 level. Based upon the difference between actual and predicted demand the deterministic model seems equally successful in predicting demand for all of the years.

The percent error between actual and predicted tillage demand is also shown in Table 4.1. During the years 1968 and 1969 the percent error exceeded 6% in only three demand periods and the error in these three demand periods was less than 14%. Considering the inherent variability in agricultural production, and thus demand for tractor hire services, the model would appear to adequately predict demand for these years. The percent error in 1966 and 1967, as indicated by Table 4.1, exceeded 15% in 6 of the 10 demand periods. This was much larger than the percent error for 1968 and 1969. However, since the difference between actual and predicted days of demand as discussed previously was not significantly different for any of the years, the model would seem to adequately predict demand for these years also. Therefore, the deterministic model, as developed in section 4.1, is accepted as a valid predictor of demand for tillage over the range of demand experienced in the Comilla Thana between 1966 and 1969.

4.3 ALLOCATIVE MODEL FOR SEASONAL DEMAND

The tractor operation model requires that the seasonal demand, which was determined using the model of section 4.1, be allocated on a daily basis. The purpose of the allocative model is to provide this daily demand for tractor services. Daily demand for tractor services in the Comilla Thana has been collected to cover a period of several years. Therefore, it is appropriate to apply statistical and mathematical techniques to derive a model which best fits this seasonal demand data.

Erlang Density Functions

Since physical and biological processes can often be represented by the Erlang family of density functions and Erlang density functions lead to aggregative models convenient to simulate, a procedure utilizing an Erlang density function was selected for simulating tractor demand. The Erlang family of density functions is given by equation 4.3.1.

$$f(t) = \frac{(ak)^k (t)^{(k-1)} e^{kat}}{(k-1)!} \qquad 4.3.1$$

where $f(t)$ = Density function

a = Parameter which determines the mean of the distributions

k = Parameter which defines the individual members of the Erlang family

t = Time

The aggregative mathematical model of a micro-process, characterized by delays which have an Erlang density function with parameters (a) and (k), is a k<u>th</u> order distributed delay with delay parameters (D_i) determined by equation 4.3.2.

$$D_i = 1/a \qquad i = 1,2, \ldots, k \qquad 4.3.2$$

The macro-process can then be described by a k<u>th</u> order linear differential equation and can be simulated using a distributed delay (Manetsch, 1972).

Distributed Delay Model

The delay process chosen to simulate daily tractor demand is referred to by Manetsch as, A Subroutine for Euler Simulation of a Distributed Delay with D Values Identical. Values of D are determined by equation 4.3.2. A subroutine for performing this simulation has been developed by Manetsch and others. For a detailed description of this subroutine see the reference, Manetsch, 1972. The application of this subroutine requires specification of the variables (VIN, VOUT, R, DEL, DT, K)

where VIN = Input variable to the delay (unlagged variable)

VOUT = Output variable from the delay (lagged variable)

R = An array of K rates determined as the output of each state of the delay process

K = Order of the delay

DT = Time increment

DEL = Delay parameter corresponding to D described in equation 4.3.2

It should be noted that the delay in an individual stage of the delay process is equal to the delay parameter (DEL) divided by the order of the delay (K).

The distributed delay subroutine described above was applied to the tractor demand simulation model. Since total seasonal demand had previously been predicted through the procedure described in section 4.1, it seemed appropriate to input this demand into the delay process as an impulse function in one time increment with the impulse equal to the total seasonal demand. Thus, in the selected time increment, VIN is set equal to the total seasonal demand expressed in days of tillage. At all of the other times, VIN is set equal to zero. The time (TI) at which the demand is introduced to the delay process is assumed to be variable for each season of each year. A time increment (DT) equal to one has been selected since this provides 1) that the time increment is compatible with the rest of the model and 2) that the output of the delay process is in tractor-days of tillage demanded each day of the season. Since the delay process contains no demand until the demand impulse function is introduced,the array of rates (R) must be initially set equal to zero. In observing actual demand the density functions seemed to have the same shape for the same seasons each year, but the shape varied from one season to the next during each year. Parameters K and DEL were therefore assumed to be different for each season during the year, but were assumed to be constant from one year to the next.

The parameters TI, K, and DEL were than determined using an iterative process such that the parameters provided the best fit to the actual tractor demand data.

Validation of the Distributed Delay Model

The distributed delay model was used to predict daily demand for tractor tillage for the years 1966 through 1969. A regression analysis was then made between the predicted demand and the actual demand. The coefficients of correlation for each season of each year for the delay model are shown in Table 4.2.

Table 4.2 Coefficients of Correlation for Delay Model Prediction of Tillage Demand

	Boro Harrow	Boro Rotary	Aus Harrow	Amon 1 Rotary	Amon 2 Rotary
1966	.75	0	0	.72	.86
1967	.65	.63	.86	.32	.70
1968	.77	.90	.88	.75	.85
1969	.72	.94	.68	0	.74

As specified in the discussion earlier the delay model used identical values for DEL and K each year for the same seasons. Only the day on which the seasonal tillage demand was put into the delay process (TI) was allowed to change from one year to the next. The values for TI, DEL, and K used in the validation test are given in Table B.3 in Appendix B.

Table 4.2 shows that the delay model had a coefficient of correlation exceeding .60 in 80% of the demand periods. Considering the variability of daily demand, a correlation of this level seemed to indicate that the distributed delay model is an adequate first approximation to daily demand.

Exponential Autocorrelation

The distributed delay model provided for no random variation in demand from one day to the next, while such a variation is easily observable in actual demand for tractor hire services. Therefore to make the model for daily demand prediction more realistic it appeared desirable to include a random variation from the demand predicted by the delay process.

The residuals (the difference between the actual and predicted demand each day) provided a measure of the random variation desired in the demand prediction model. Observation of the residuals often indicated several days of higher than average demand followed by several days of lower demand thus indicating the possibility of autocorrelation. The Durbin-Watson test for first-order linear autocorrelation has been designed for analysis of residuals (Kane, 1968). The statistic (d) for this test is given by equation 4.3.3.

$$d = \frac{SS\ (R - \text{previous } R)}{SS\ (R)} \qquad 4.3.3$$

where d = Durbin and Watson test statistic

SS = Sum of squares

R = Residuals

The Durbin-Watson statistic and the critical test statistic for each season is shown in Table 4.3.

Table 4.3 Test for First Order Linear Autocorrelation

		Boro Harrow	Boro Rotary	Aus Harrow	Amon 1 Rotary	Amon 2 Rotary
1966	d	.88	--	--	1.23	1.24
	d critical	1.58	--	--	1.53	1.54
1967	d	.91	.93	1.20	1.15	1.07
	d critical	1.58	1.58	1.45	1.53	1.54
1968	d	.71	1.18	.64	.76	1.54
	d critical	1.58	1.58	1.45	1.53	1.54
1969	d	1.28	.91	.87	--	1.03
	d critical	1.58	1.58	1.45	1.53	1.54

The hypothesis of positive autocorrelation is accepted when d is less than d critical. Table 4.3 indicates that for all seasons there is a positive autocorrelation. Thus, autocorrelation has been included as part of the model for simulating demand for tractor hire services.

The Durbin-Watson statistic (d) has been found to be quite closely related to first order linear autocorrelation for large samples. For large samples, the Durbin-Watson test statistic is calculated by equation 4.3.4 (Kane, 1968).

$$d = 2(1-r(1)) \quad 4.3.4$$

where d = Durbin and Watson test statistic

$r(1)$ = First order linear autocorrelation coefficient

The first order linear autocorrelation coefficient, which is required for simulating autocorrelation, can then be determined from the Durbin-Watson test statistic by using equation 4.3.5.

$$r(1) = 1 - \frac{d}{2} \quad 4.3.5$$

Several persons have developed procedures for including autocorrelation in simulations. The method chosen for this model was developed by Manetsch and is entitled, A Subroutine for Generating Exponentially Autocorrelated Random Variables. For purposes of this discussion only the values required by the subroutine are presented here. For a detailed discussion of the subroutine see the reference, Manetsch, 1972. The values required by the subroutine are (XLMDA, VAR, DT, I, U)

where XLMDA = First order autocorrelation coefficient desired in the simulation

VAR = Variance desired in the simulation

DT = Time increment

I = A variable with initial value equal to zero

U = Random variable which has zero mean variance (VAR) and correlation coefficient (XLMDA)

In applying autocorrelation to the tractor demand model the Durbin-Watson test statistics shown in Table 4.3 and equation 4.3.5 (where r(1) is replaced by XLMDA) were used to calculate values for XLMDA. For application in the model it appeared desirable that XLMDA be made independent of the year of the simulation. Since the autocorrelation coefficient for the same season from one year to the next was approximately constant the mean values determined from the several years of available data have been used in the model. The values of XLMDA determined for the model are given in Table B.4 of Appendix B.

As with the autocorrelation coefficient it appeared desirable that the variance (VAR) used by the autocorrelation subroutine be dependent only upon the season and not upon the year of the simulation. The standard deviation between actual tillage demand and demand predicted by the delay model was available. Observation of the standard deviation of these residuals over several years of data seemed to indicate a linear relationship between the size of the standard deviation and the size of the seasonal demand. The first order linear equation 4.3.6 is then used for determining standard deviation. The variance (VAR_i) used by the autocorrelation subroutine is then calculated as the square of the standard deviation as indicated in equation 4.3.7.

$$SD_i = a_i + b_i DMD_i \qquad i = \text{season} \qquad 4.3.6$$

$$VAR_i = (SD_i)^2 \qquad i = \text{season} \qquad 4.3.7$$

where VAR_i = Variance desired by the subroutine

a_i = Intercept of variance line

b_i = Slope of variance line

DMD_i = Demand for tractor tillage as predicted by the deterministic demand model

SD_i = Standard deviation

The slope b_i and intercept a_i for each season is shown in Table B.4 of Appendix B. A correlation analysis of the predicted variance based upon equations 4.3.6 and 4.3.7 and the variance determined from the residuals for the years of available data is shown in Table 4.4.

Table 4.4 Correlation Analysis of Variance Prediction

Season	Coefficient of Correlation
Boro Harrow	.75
Boro Rotary	.98
Aus Rotary	.74
Amon 1 Rotary	1.00
Amon 2 Rotary	.99

As can be seen from Table 4.4 for three of the five seasons the correlation coefficient exceeds .98 and in the other two seasons is approximately .75. These results seem to justify the use of equations 4.3.6 and 4.3.7 to determine the desired variance for the autocorrelation subroutine.

The time increment (DT) for the autocorrelation subroutine was set equal to 1, the time increment used in the rest of the model.

Based upon the above values of XLMDA, VAR, DT, and I the desired autocorrelated random variable U is determined. To incorporate the random variable into the model for predicting demand, (U) is added to the demand predicted by the delay model as shown in equation 4.3.8.

$$DTR = VOUT + U \qquad 4.3.8$$

where DTR = Daily tractor demand

VOUT = Daily tractor demand predicted by the delay model

U = Exponentially autocorrelated random number with variance (VAR) and zero mean

Since actual tractor demand is hired for a minimum of one half of a day, the daily tractor demand (DTR) is set equal to the nearest half day for use in the tractor operation model.

4.4 VALIDATION OF THE ALLOCATIVE AND THE COMBINED DETERMINISTIC AND ALLOCATIVE DEMAND MODELS

Validation of the allocative model for distributing demand requires 1) that the allocative model does not significantly change the demand predicted by the deterministic model and 2) that the delay and autocorrelation subroutines adequately distribute demand on a daily basis throughout each season.

The simulation run was made with 100 iterations of the allocative model in order to test that the allocative model did not significantly change the demand predicted by the deterministic model. This run simulated four years of tractor hire service demand in the Comilla Thana, Bangladesh. The results of the run are shown in Table 4.5. This table shows that in only 10% of the seasons during the four years of the simulation was the deterministic value more than one standard deviation from the mean of the values predicted by the allocative model. Therefore the conclusion can be made that the allocative model distributes demand without altering the value of demand coming from the deterministic model.

Table 4.6 shows the actual demand for tractor hire service in the Comilla Thana from 1966-1969 and the expected demand predicted by the combined deterministic and allocative models. In 55% of the seasons during the four years shown in Table 4.6 the actual demand was within one standard deviation of the expected value of demand as predicted by the model. The model seems especially accurate for the years 1968 and 1969 where the actual demand was within one standard deviation of the predicted value for 80% of the seasons and within two standard deviations for the other 20% of the seasons. For all of the years the actual value lay outside three standard deviations of the predicted values in only 10% of the seasons. Thus, the combined allocative and deterministic models appear to validly predict seasonal demand for tillage.

The second validation test concerns the distribution of the demand on a daily basis. To test this, the model was run to simulate four years of demand and the number of tractor days demanded each day for each season was predicted. The actual and expected number of days on which a

Table 4.5 Days of Demand Predicted by the Deterministic Model and Expected Demand Based Upon 100 Iterations of the Allocative Model

	1966			1967			1968			1969		
	Pre-dict	Distri-buted	Std dev	Pre-dict	Distri-buted	Std dev	Pre-dict	Distri-buted	Std dev	Pre-dict	Distri-buted	Std dev
Boro												
Harrow	59.6	55.18	10.31	101.5	87.31	13.66	151.9	147.92	18.46	167.8	174.45	19.69
Rotary	13.4	13.04	3.83	39.5	31.73	5.91	146.1	137.73	11.09	299.8	293.41	14.69
Aus												
Harrow	84.1	77.75	9.20	141.9	134.65	15.05	200.6	212.24	26.16	163.3	165.16	18.79
Amon 1												
Rotary	33	38.34	6.53	63.3	67.47	9.59	114.4	118.37	15.24	165.8	172.30	17.60
Amon 2												
Rotary	49.9	45.13	5.18	74.4	73.02	7.19	94.8	95.76	9.95	116.2	122.84	11.39

Table 4.6 Days of Actual Demand for Tractor Tillage and Expected Demand Predicted by the Demand Model

	1966			1967			1968			1969		
	Actual	Predict	Std dev	Actual	Predict	Std dev	Actual	Predict	Std dev	Actual	Predict	Std dev
Boro												
Harrow	74	55.18	10.31	106.5	87.31	13.66	174	147.92	18.46	159	174.45	19.69
Rotary	4.5	13.04	3.83	53	31.73	5.91	153.5	137.73	11.09	290	293.41	14.69
Aus												
Harrow	78	77.75	9.20	112	134.65	15.05	227.5	212.24	26.16	160.5	165.16	18.79
Amon 1												
Rotary	34	38.34	6.53	60	67.47	9.59	103.0	118.37	15.24	156.5	172.30	17.60
Amon 2												
Rotary	65	45.13	5.18	89.5	73.02	7.19	91.5	95.76	9.95	112	122.84	11.39

given number of tractor days of demand occured during the Aus season in the Comilla Thana is shown in Table 4.7. The expected values are based upon 100 iterations of the model for each year, 1966 through 1969. Similar tables for all of the seasons are included in Tables B.5 through B.10 of Appendix B.

In Table 4.7 demand has been divided into increments of one tractor-day. The actual and expected number of days on which this number of tractor-days is demanded is shown in Table 4.7 as columns 1 and 2 of each year. For example, in 1966 there were 13 days on which fewer than two days of tractor tillage were demanded. Based upon the model one could expect 12.13 days, with a standard deviation of 2.66 days, on which fewer than two days of tractor tillage would be demanded. Thus, the actual number of days on which this demand occured is within one standard deviation of the expected value. The validity of the model can then be established by considering the proportion of actual demand which falls within a given standard deviation of the expected value. Table 4.8 shows this proportion for each season over the four years of the simulation.

Table 4.8 shows that during the years 1968 and 1969 only 5% of the actual observations exceeded the estimated by more than three standard deviations and 56% of the actual observations fell within one standard deviation of the estimated values. Thus, the combined models were quite accurate in predicting daily demand for tractor services and can be considered valid for these years. The allocative model performed less

Table 4.7 Expected and Actual Number of Days during Aus Season on which the Given Number of Tractor Days of Tillage were Demanded in the Comilla Thana

Demand Tractor-Days	Number of days on which given demand occurs											
	1966			1967			1968			1969		
	Actual	Predict	Std dev	Actual	Predict	Std dev	Actual	Predict	Std dev	Actual	Predict	Std dev
< 2	13	12.13	2.66	14	9.12	2.16	6	8.45	2.18	11	10.16	2.68
2 < 3	6	4.61	2.24	6	4.03	1.88	4	5.24	2.22	5	5.93	2.39
3 < 4	3	4.08	1.98	9	3.08	1.92	2	4.03	2.24	2	3.67	2.12
4 < 5	2	4.69	2.03	4	2.55	1.60	0	2.65	1.60	0	2.55	1.70
5 < 6	0	2.89	1.44	3	2.68	1.56	3	2.08	1.61	3	2.14	1.58
6 < 7	4	1.20	1.28	1	2.85	1.70	1	1.77	1.42	6	2.24	1.54
7 < 8	0	.07	.29	0	2.34	1.25	1	1.90	1.43	3	2.35	1.89
8 < 9				0	2.27	1.39	4	1.83	1.11	2	2.25	1.43
9 < 10				0	1.86	1.30	0	1.95	1.36	1	2.06	1.32
10 < 11				0	.72	.82	4	1.71	1.35	2	1.50	1.24
11 < 12				0	.32	.55	2	1.48	1.28	1	1.25	1.12
12 < 13				0	.01	.10	3	1.65	1.23	0	.65	.91
13 < 14							0	1.19	1.09	0	.23	.51
14 < 15							2	.91	1.06	0	.03	.17
15 < 16							1	.73	.92			
16 < 17							0	.24	.49			
17 < 18							0	.11	.42			

Table 4.8 Observations Each Year in Which the Actual Number of Days on Which Demand for a Specified Number of Tractor-days Occurred Deviated From the Estimated by the Given Standard Deviation

Standard deviation of actual from expected	Boro Harrow	Boro Rotary	Boro Total	Aus Harrow	Amon 1 Rotary	Amon 2 Rotary
1966						
< 1	--	--	--	57%	--	25%
1 < 2	--	--	25%	29%	--	--
2 < 3	50%	--	25%	14%	--	25%
> 3	50%	100%	50%	--	100%	50%
1967						
< 1	40%	100%	33%	42%	67%	75%
1 < 2	--	--	17%	42%	33%	--
2 < 3	20%	--	17%	8%	--	--
> 3	40%	--	33%	8%	--	25%
1968						
< 1	--	43%	70%	53%	33%	50%
1 < 2	33%	43%	10%	47%	--	--
2 < 3	67%	--	10%	--	66%	17%
> 3	--	14%	10%	--	--	33%
1969						
< 1	58%	67%	64%	86%	38%	66%
1 < 2	28%	8%	40%	7%	50%	17%
2 < 3	14%	25%	--	7%	--	17%
> 3	--	--	16%	--	12%	--
Total						
< 1	27%	59%	48%	60%	39%	55%
1 < 2	32%	18%	23%	32%	22%	5%
2 < 3	23%	14%	9%	6%	22%	15%
> 3	18%	9%	20%	2%	17%	25%

accurately for the years 1966 and 1967. Since the deterministic model also performed less accurately when predicting demand for these years at least part of the error in the allocative model can be attributed to the deterministic model. On the whole the allocative model and the combined deterministic and allocative models seem to be a valid representation of daily demand over the range of demand experienced in the Comilla Thana between 1966 and 1969.

CHAPTER 5

5.0 INTRODUCTION

The repair model, in order to be compatible with the tractor operation model, has to 1) predict the occurrence of the breakdown of individual tractors, 2) predict the duration of repair once a breakdown occurs, and 3) predict the cost of repairing the breakdown. Hunt, in a study of machinery repair on farms in Illinois and Indiana, found that the frequency of repairs seemed to be related to the accumulated use of a machine. Average duration of repairs was also related to accumulated machine use. He concluded that while there seemed to be some relationship between breakdown incidence and the use and age of a machine, that in reality breakdowns were highly random in nature (Hunt, 1970).

The probability of repair occurring on any given day during one hundred day intervals of accumulated tractor operation for farms in Indiana and Illinois and for the tractor hire service in Comilla, Bangladesh is shown in Figure 5.1. The U.S. curve is based upon data collected by Hunt (Hunt, 1970).

It is obvious from Figure 5.1 that the probability of a tractor breakdown at Comilla is much larger than on farms in the U.S.. Thus, breakdown frequency appears to be country specific. For a simulation model to accurately simulate the occurrence of tractor and machinery breakdowns in developing countries it must be based upon the repair information of those countries. Similar conclusions can be drawn concerning repair duration and cost. In Chapter 2 it was noted that the

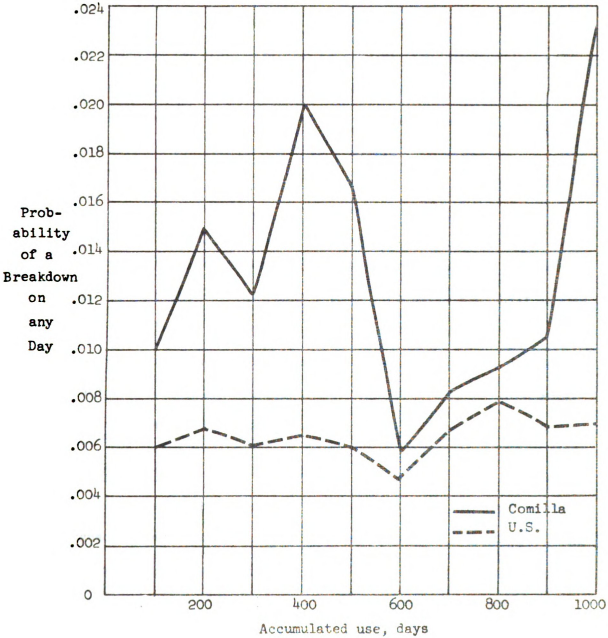


Figure 5.1 Probability of Tractor Breakdown on Any Day of Tractor Operation as a Function of Accumulated Days of Tractor Use

cost of repairs in the tractor hire service was about 100% greater at Comilla than in the U.S.. Also while tractor repair time is often measured in hours in the U.S., tractor repairs at Comilla usually required days and sometimes months to be completed. Therefore the repair records of tractors operated by the Comilla tractor hire service have been used to develop the repair prediction model.

5.1 ANALYSIS OF BREAKDOWNS

A detailed analysis of demand for tractor services, prior to model construction, identified several basic demand components and their interconnections. This led to the development of the structural demand model discussed in Chapter 4. A similar analysis of the repair data of the Comilla tractor hire service was performed. The objective of this analysis was to develop a model for simulating tractor breakdowns and repairs.

Tractor Type Comparison

The Comilla tractor hire service has over the years mainly operated Massey Ferguson 35 and Massey Ferguson 135 tractors. The Massey Ferguson 135 (MF 135) was a newer model tractor of similar design and horsepower as the Massey Ferguson 35 (MF 35) and replaced the MF 35 tractors when they no longer performed reliably. Since both the MF 35 and MF 135 tractors were made by the same manufacturer and were of similar design, it was anticipated that they might have similar repair characteristics. This would then justify the use of one repair model to simulate the repair behavior of all tractors in the Comilla tractor hire service.

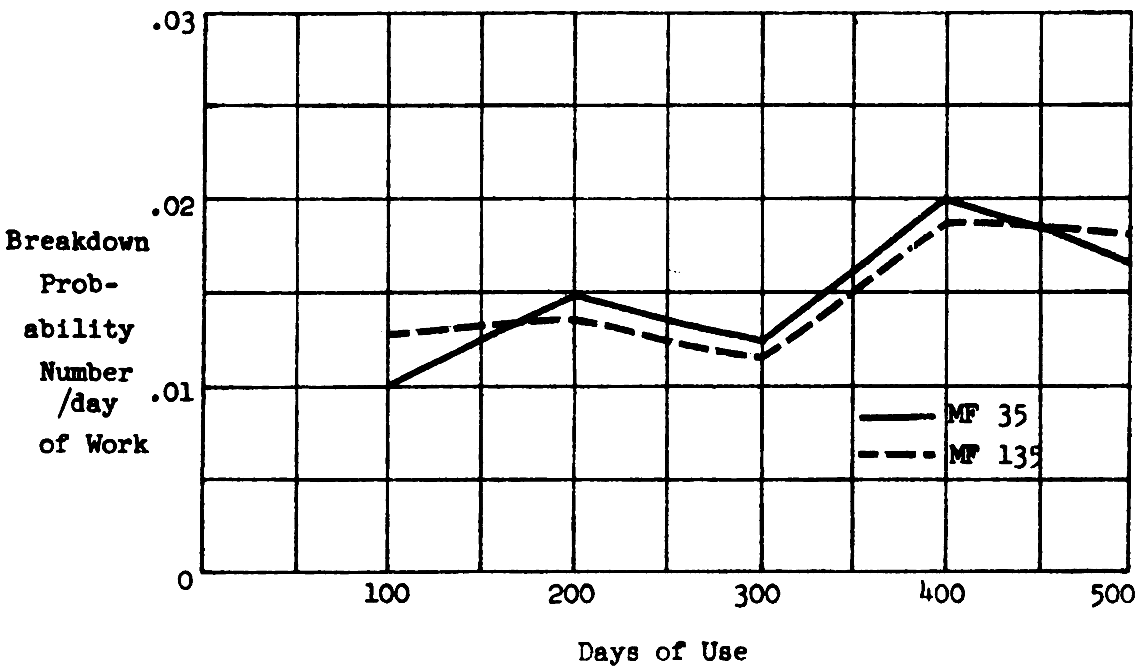


Figure 5.2 Probability of Repair as a Function of the Days of Tractor Operation

Figure 5.2 shows the probability of a breakdown occurring to an individual tractor on any given day as a function of the accumulated days of tractor operation. This comparison shows that the probabilities were very similar for the two types of tractors. A correlation analysis was made between the two curves and indicated a correlation of .84. This analysis would seem to justify the use of one model to predict the occurrence of repair for both tractor types. It should be noted that at the time of this study that each MF 135 tractor had worked between 400 and

500 days. Thus, this comparison is based upon only a portion of their expected life. The existing evidence made it impossible to conclude that the two tractor types would continue to exhibit similar repair behavior. In the absence of contradictory evidence, however, the applicability of one model for predicting repair occurrence for both types of tractors was accepted.

The accumulated per cent of all repairs as a function of the duration of repairs is shown in Figure 5.3. In this figure it can be seen that a slightly larger percent of the MF 35 tractor repairs were of shorter duration than were repairs of the MF 135 tractors. For example 61% of the MF 35 tractor repairs were less than ten days in length while 57% of the MF 135 tractors had repairs of less than ten days. The mean duration of repairs for the MF 35 tractors was 16.77 days compared to a mean repair duration of 22.14 days for the MF 135 tractors. However, this difference in mean repair duration between the two types of tractors was not significant at the .05 level. Therefore, the development of one model to simulate the duration of repairs for both types of tractors seemed acceptable.

The cost of repairs for the two types of tractors was also studied. The mean cost per major repair for repairs made during the first 500 days of use was approximately $47.00 (Rs. 218) per repair for the MF 35 tractors and $43.00 (Rs. 201) per repair for the MF 135 tractors. The difference in repair cost was not significant at even the .5 level. Therefore, developing one model to simulate the repair cost for both types of tractors seemed justified.

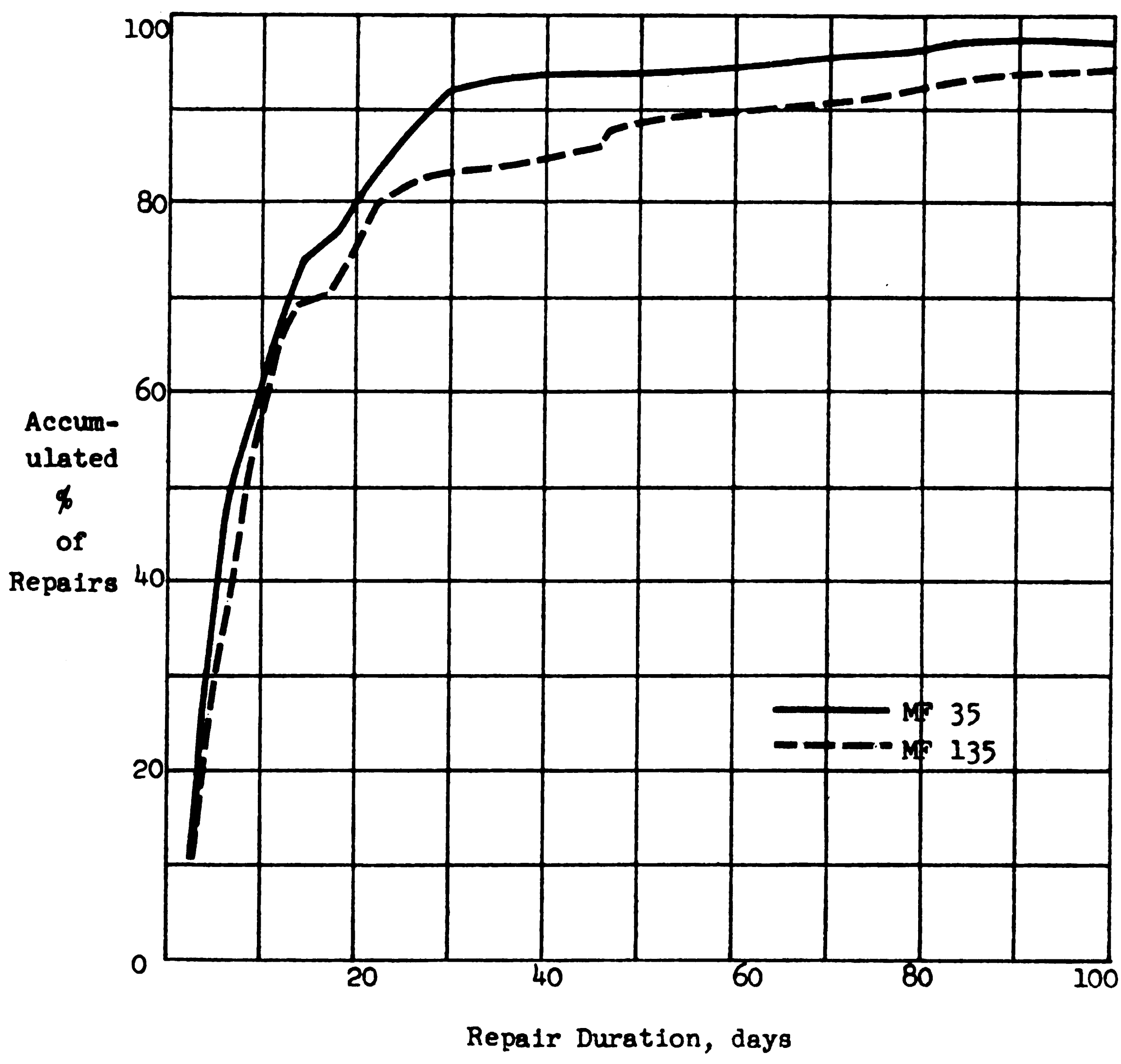


Figure 5.3 Accumulated Percent of Repairs as a Function of Repair Duration During the First 400 Days of Tractor Work

In Chapter 3 it was stated that within a single simulation run of the model, tractor size remains constant. Therefore the preceding discussion justifies the assumption made in the model that tractors purchased at different times during the simulation will exhibit similar repair occurrences, durations, and costs.

Type of Repairs

Repairs occurring to tractors at Comilla were classified into five major types: general overhaul, electrical, engine, hydraulic, and power transmission. The percent of total repair occurrences and the percent of total repair costs with the above classifications are shown in Table 5.1.

Table 5.1 Percent of Repair Occurrence and Cost with a Given Repair Description

Description	% Occurrence	% Cost
General Overhaul	4.0	45.1
Electrical	44.4	16.5
Engine	5.2	6.0
Hydraulic	14.4	18.6
Power Transmission	17.1	7.5
Other	14.9	6.3

Table 5.1 indicates that the tractor's electrical system was involved in over 44% of the repairs. These repairs however were of a less serious nature and only made up 16.5% of repair costs. Breakdowns which resulted

in a tractor overhaul occurred infrequently but were by far the most expensive, making up 45.1% of the total tractor repair cost.

The breakdown of the tractors can be attributed to three major causes. The first cause, inadequate machine design, is probably the largest contributor to electrical problems. The humid environment and the operation of the tractors in flooded fields causes rubber and insulation around electrical wiring to deteriorate rapidly. The second cause, inadequate standards for fuels and lubricants, probably is the largest factor in the need for tractor overhauls and hydraulic problems. The quality of fuels and lubricants in Bangladesh was neither adequately standardized nor controlled. Excessive wear on tractor moving parts thus resulted when these lubricants broke down at high operating temperatures. The third cause which contributed to power transmission problems including clutch and brake problems was abuse by the machine operator. An inadequately trained tractor operator tends to lock the brakes when stopping and keep his foot on the clutch during tractor operation which shortens the life of these machine parts.

A number of the above problems could be reduced through adequate standards and improved training techniques. These in turn should reduce the occurrences of breakdowns, the repair durations, and the repair costs. The model has therefore been designed to evaluate changes in repair occurrence, duration, and cost resulting from better training programs and improved petroleum products.

5.2 PREDICTION OF THE OCCURRENCE OF A BREAKDOWN

In predicting the occurence of a breakdown in the model it has been assumed, based upon conclusions drawn from the U.S. experience, that the probability of a breakdown is related to tractor use. The method chosen to relate tractor use to repair occurrence was a curve fitting approach using least squares regression. The model which seemed to best fit the tractor repair data of Comilla was a least squares equation using a 4th order polynomial as shown in equation 5.2.1. This equation is used in the model for predicting the probability of a major breakdown occurring for each day of tractor use. A major breakdown is defined as a breakdown requiring more than one day to repair. Field breakdowns, those requiring only one day for repair, are discussed later in this section.

$$PROB = b_1 + b_2t + b_3t^2 + b_4t^3 + b_5t^4 \qquad 5.2.1$$

where PROB = Probability of a breakdown occurring on day t given that the tractor was operatable at beginning of day t

$b_1 \ldots b_5$ = Partial regression coefficients for each power of t

t = Accumulated number of days a tractor has worked

The curve was fitted by first determining the probability of a major repair occuring per day (P(t)) during intervals of 20 days of tractor work, as shown in equation 5.2.2.

$$P(t)_i = \frac{NB_i}{NT_i * 20} \qquad 5.2.2$$

where $P(t)_i$ = Probability of a repair occurring on any day for an individual tractor during interval i

i = Interval of accumulated tractor work measured in 20 day increments

NB_i = Number of breakdowns occurring to all tractors during interval i

NT_i = Number of tractors which had accumulated work days in interval i

20 = Number of days of tractor work per tractor in interval i

A plot of the probabilities and the 4th order polynomial fitted through them is shown as Figure C.1 of Appendix C. The partial correlation coefficients ($b_1 \ldots b_5$) for the equation are given in Table C.1 of Appendix C. The coefficient of correlation between the probabilities and the curve was .41.

In the simulation program the probability of a major repair occurring is predicted by entering the accumulated days an individual tractor has worked into equation 5.2.1 as the value of t. This t value predicts a probability of a repair occurring to that tractor on that day. Next the probability is adjusted for the length of the workday after which a random number from a list of uniformly distributed random numbers from zero to one is selected and compared to the probability value. If the random number is less than the probability value, the simulation assumes a breakdown has occurred and the model proceeds to the prediction of repair duration and cost. If the value of the random number is larger than the probability value, the simulation assumes that a major breakdown did not occur on that day and the tractor remains eligible for work. This procedure is repeated for additional tractors until all of the work on a given day has been assigned.

In an actual tractor hire service the working condition of idle tractors is not usually determined. This behavior is simulated in the model by checking for the occurrence of a breakdown only for those tractors which are to be assigned work.

Probability Adjustment for Day Length

Previously it was mentioned that the probability of a breakdown occurring was to be adjusted for the length of the workday. This is done because the Comilla tractor hire service, on which the model is based, had a 10 hour workday, while in the model the working hours per day can be varied. It was assumed in the model that the longer the working hours per day the higher should be the probability of a breakdown on that day. Therefore, it was necessary to alter the probability of a breakdown to correspond with the length of the workday.

Reliability theory provides a method for adjusting probabilities of breakdowns for varying time periods (Rau, 1970). The relationship between the probability of a breakdown in a small time increment (dt) and the probability of a breakdown during one day is given in equation 5.2.3.

$$P(t) = 1 - \exp(-\int_{t}^{t+1} \lambda(t)dt) \qquad 5.2.3$$

where $P(t)$ = Probability of a breakdown on day t

exp = Exponential

$\lambda(t)dt$ = Probability of a breakdown in time interval t to t + dt given that the machine is operating at time t

Assuming λ is independent of time and integrating, then results in equation 5.2.4.

$$P(t) = 1 - \exp(-\lambda t) \qquad 5.2.4$$

The value of λ can be solved for in terms of P(t) as shown in equation 5.2.5.

$$\lambda = \frac{-\log(1-P(t))}{t} \qquad 5.2.5$$

Finally, for time interval T the probability of a breakdown is given by equation 5.2.6.

$$P(T) = 1 - \exp(\log(1-P(t)) * \frac{T}{t}) \qquad 5.2.6$$

where $P(T)$ = Probability of a breakdown during day of length T

exp = Exponential

log = Natural logarithm

$P(t)$ = Probability of a breakdown during day of length t

In the simulation model the probability of a breakdown occurring during a day with the desired number of working hours is calculated by letting P(t) = probability of breakdown during a 10 hour day, t = 10 and T = Number of working hours in the day length desired.

In the model it is desired that changes in the probability of a breakdown be evaluated. Therefore, the model allows the breakdown probability from equation 5.2.6 to be multiplied by a factor in increase or decrease the probability of repair.

Field Breakdowns

Field breakdowns, those requiring only one day to repair, are handled in the model similarly to the major breakdowns. The probability of a field breakdown based upon the Comilla data, however, seemed to be constant over time and thus independent of accumulated tractor work. The value for the probability of a field breakdown (PROBFR) in the model was .05. The occurrence of a field repair was obtained in the model by replacing P(t) with PROBFR in equation 5.2.6 and then following the same procedures discussed for major repairs.

5.3 PREDICTION OF REPAIR DURATION

When the occurrence of a breakdown has been predicted, the next step is to determine the duration of the repair. It was assumed that the proportion of repair with a given duration might change with the accumulated number of days worked. Therefore, the duration of the repairs in each 200 day period of accumulated tractor work was identified. The repair durations were then determined as a function of the accumulated percent of repairs for each 200 day period. The plot of these functions is shown in Figures C.2 through C.4 in Appendix C. The shape of these curves suggested the applicability of an exponential least squares model. Equation 5.3.1 shows the form of the function chosen to relate repair duration and the accumulated percent of repairs.

$$DUR_i = a_i * \exp(b_i * PCR^2) \qquad 5.3.1$$

where

- i = Appropriate 200 day period of accumulated tractor work
- DUR_i = Duration of the repair for tractor work period i, days
- a_i = Parameter which determines the intercept of the curve for work period i
- exp = Exponential
- b_i = Parameter which determines the shape of the curve for work period i
- PCR = Accumulative proportion of repairs for the given repair duration (decimal percent)

Using this equation, the values of the parameters, a_i and b_i, that determined the best fit of the actual repair durations to the accumulated percent of repairs for each period of accumulated tractor work were found. The a_i and b_i values and the correlation coefficient between the curves and the equation is shown in Table C.2 of Appendix C. Correlation coefficients between the actual values and the best fit exponential curve were between .95 and .99. This high correlation seemed to justify developing the repair duration model based upon the least squares exponential as shown in equation 5.3.1. This equation is implemented in the model by first determining the appropriate set of parameters, a_i and b_i, for the accumulated work which has been performed by the tractor. For example, if the tractor has performed 650 days of work this puts the tractor in the 4th 200 day period of tractor work and the appropriate set of parameters a_i and b_i are those corresponding to $i = 4$.

Second, a uniformly distributed random number (RN) between zero and one is selected from a list of random numbers. By using this random number in place of PCR in equation 5.3.1 and by using the set of parameters selected above, an individual repair duration is calculated.

Validation of the Repair Duration Model

If the model is a valid representation of actual repair duration, then the percent of actual repairs within a given range of durations would be the same as the percent of predicted repairs. Therefore, to validate the model, six different ranges of repair durations were selected for each 200 day period of tractor operation and the percent of actual repairs with durations within each range were calculated. These values are shown in Table 5.2. The model was then used and the percent of predicted repairs with durations within each range were calculated. By running the model repetitively a mean and standard deviation of the percent of repairs within each range was determined. This mean and standard deviation are also shown in Table 5.2.

Table 5.2 Percent of Tractor Repairs Within Indicated Ranges of Repair Durations for Each 200 Day Period of Accumulated Tractor Work for MF 35 Tractors

Tractor Work Days	% of Tractor Repairs in Each Range					
	Repair Duration Range, days					
	< 6	6-10	11-20	21-50	51-100	>100
0 - 200						
Actual	38	17	22	8	9	6
Best Fit						
mean	43	16	11	11	10	7
std dev	8	8	5	5	6	5
201 - 400						
Actual	39	28	11	22	0	0
Best Fit						
mean	41	27	18	13	0	0
std dev	5	5	4	4	0	0
401 - 600						
Actual	37	20	10	20	0	13
Best Fit						
mean	43	15	11	11	8	12
std dev	8	4	4	6	4	5
601 - 800						
Actual	19	19	24	14	5	19
Best Fit						
mean	26	24	14	15	9	12
std dev	9	11	7	7	5	8
801 - 1000						
Actual	24	24	9	5	14	24
Best Fit						
mean	24	21	15	16	10	15
std dev	8	7	6	6	4	6
1001 - 1200						
Actual	36	14	7	14	23	6
Best Fit						
mean	25	23	15	17	11	10
std dev	6	5	4	5	4	4

Comparing the mean values of percent of predicted repairs in each range duration for the 0-200, 201-400, and 401-600 day period of tractor operation indicated a close similarity in the values. For example, the percent of predicted repairs less than six days in duration was 43%, 41%, and 43% for the 0-200, 201-400, and 401-600 day periods of accumulated tractor work respectively. A similar comparison of the mean values of percent of predicted repairs in each range of repair duration for the 601-800, 801-1000, and 1001-1200 work day periods also indicated a close similarity between the predicted values. The percent of repairs less than six days in duration was between 24 and 26% for all three periods of accumulated tractor work greater than 600 days. Therefore, it appeared possible that one set of parameters might be appropriate for all workday periods with accumulated work less than 600 days and a second set for accumulated work greater than 600 days. A set of parameters was therefore determined for these two periods of accumulated tractor work. The parameters determined for the 0-600 day period of tractor work had the same value as the parameters for the 0-200 day period and the parameters for the 601-1200 day period of tractor work had the same value as the parameters for the 601-800 day period. In the following discussion the model, using only these two sets of parameters is referred to as the combined model.

The validity of both the best fit and combined models was tested by comparing the number of standard deviations the percent of actual repairs in a given range of repair duration was from the percent predicted by the models. The results of this validity test are shown in Table 5.3.

Table 5.3 Number of Standard Deviations Percent of Actual Repair is From Percent of Predicted Repairs for MF 35 Tractors

Tractor Work Days	Number of Standard Deviations					
	Repair Duration Range, days					
	< 6	6-10	11-20	21-50	51-100	> 100
0 - 200						
Best Fit	1	1	3	1	1	1
Combined	1	1	3	1	1	1
201 - 400						
Best Fit	1	1	2	3	1	1
Combined	1	2	1	2	2	2
401 - 600						
Best Fit	1	2	1	2	2	1
Combined	1	1	1	2	2	2
601 - 800						
Best Fit	1	1	2	1	1	1
Combined	1	1	2	1	1	2
801 - 1000						
Best Fit	1	1	1	2	1	2
Combined	1	1	1	2	1	2
1001 - 1200						
Best Fit	2	2	2	1	3	1
Combined	2	1	2	1	3	2

Table 5.3 shows that both the best fit model and the combined model are quite accurate in predicting repair duration for each period of tractor work. Using the best fit model the percent of predicted repairs within each range of durations was within one standard deviation of the actual value 64% of the time and within two standard deviations 92% of the time. The combined model was approximately as accurate being within one standard

deviation 56% of the time and within two standard deviations 95% of the time. There did not seem to be a measurable difference between the individual model and the combined model. The parameters for the combined model were therefore chosen for use in the repair duration prediction model.

The preceding discussion dealt only with the MF 35 tractors. The validity of the combined model for the MF 35 tractors when applied to the MF 135 tractors was also tested. The results of this test are shown in Table 5.4 and Table 5.5.

Table 5.4 Percent of Tractor Repairs Within Indicated Ranges of Repair Durations for Each 200 Day Period of Accumulated Tractor Work for MF 135 Tractors

Tractor Work Days	% of Tractor Repairs in each Range					
	Repair Duration Range, days					
	< 6	6-10	11-20	21-50	51-100	> 100
0 - 200						
Actual	39	25	9	16	4	7
Best Fit						
mean	39	17	12	14	10	8
std dev	6	7	5	6	6	5
201 - 400						
Actual	25	30	22	12	4	7
Best Fit						
mean	25	25	15	18	12	5
std dev	8	6	5	6	6	2

Table 5.5 Number of Standard Deviations the Percent of Actual Repair is From the Predicted Percent for MF 135 Tractors

Tractor Work Days	Number of Standard Deviations					
	Repair Duration Range, days					
	< 6	6-10	11-20	21-50	51-100	> 100
0 - 200						
Best Fit	1	2	1	1	1	1
Combined	1	2	1	1	1	1
201 - 400						
Best Fit	1	1	2	1	2	1
Combined	3	2	3	1	1	1

As can be seen from Table 5.5, the percent of predicted repairs within each range of durations, using the best fit model for the MF 135 tractors was within 1 standard deviation of the actual value 75% of the time and within 2 standard deviations 100% of the time. The combined model when applied to the MF 135 tractors was only slightly less accurate being within one standard deviation 67% of the time and within 2 standard deviations 84% of the time. These results substantiate the assumption made in section 5.1 that the same model could be used for both MF 35 and MF 135 tractors.

Since the combined model for predicting repair duration seemed to provide the necessary accuracy, it was selected for use in the simulation model. The values of the parameters for the repair duration model are shown in Table C.3 of Appendix C.

5.4 REPAIR COST MODEL

In predicting the cost of a breakdown it was initially assumed that the cost of a present repair might be related to the past repair history of the tractor. A least squares regression analysis was made with cost of the present repair as the dependent variable and the following factors as independent variables, 1) total accumulated number of days the tractor has worked prior to the present repair, 2) duration of the present repair, 3) duration of the previous most recent repair, 4) number of days the tractor has worked since the last repair, 5) number of calendar days since the last repair, 6) cost of the previous repair, 7) the total accumulated repair cost prior to the present repair, and 8) total calendar days the tractor has been in the tractor hire service. The regression analysis found that duration of the present repair was the only factor significantly related to cost of the present repair at the .05 level. The multiple correlation coefficient between all of the factors described above and the cost of the present repair was found to be .768. The partial correlation coefficient with only repair duration considered was .722. The repair duration was also the only factor whose simple correlation was greater than .36. Based upon this analysis, the conclusion was made that repair cost should be based only upon duration of the present repair and all of the other factors could be neglected.

Cost Model Development

Based upon the preceding conclusion another least squares regression analysis was performed with repair cost as the dependent variable and duration of repair as the independent variable as shown in equation 5.4.1.

$$COST_i = a_1 + a_2 (DUR_i)^b \qquad 5.4.1$$

where $COST_i$ = Total cost of repair i

a_1, a_2 = Regression coefficient

b = Factor to which the duration is raised

DUR_i = Duration of repair i

For the first attempt at fitting repair duration to actual, b was set equal to 1 in equation 5.4.1. An examination of the residuals using this model indicated that for the repairs with the longer durations, the model was consistently predicting costs larger than the actual. This implied that the model could be improved by making b less than 1. The b value chosen for use in the repair cost model of the tractor hire service simulation was b = .5. The multiple correlation between actual cost and cost predicted using actual duration was .68 when b was set equal to .5. The values of parameters a_1 and a_2 used in equation 5.4.1 for the repair cost model are given in Table C.4 of Appendix C.

The cost model using equation 5.4.1 predicts one cost for all repairs of a given duration. Since in actual practice repairs with the same duration usually do not have the same cost, the simulation model required a method for predicting different cost for repairs of similar duration. To do this, repairs with durations within specified ranges were grouped together. The ranges in repair duration were: less than 2 days, 3-5 days, 6-10 days, 11-20 days, 21-50 days, 51-100 days, and greater than 100 days.

The ratio of actual cost of repair and the cost predicted by equation 5.4.1, using actual durations, was calculated for each repair as shown in equation 5.4.2.

$$X_{ij} = \frac{ACOST_{ij}}{COST_{ij}} \qquad 5.4.2$$

where X_{ij} = Ratio of actual to predicted cost

i = Identification of individual repairs

j = Identification of the repair duration range

$COST_{ij}$ = Cost of repair i in range j predicted from actual repair durations by equation 5.4.1

$ACOST_{ij}$ = Actual cost of repair for repair i in range j

The X_{ij} values were than determined as a function of the accumulated percent of repairs in each repair duration range. These values are shown in Table C.5 of Appendix C. The X_{ij} values were then fitted to accumulative percent of repairs using a least squares exponential model as shown by equation 5.4.3.

$$X_j = c_{1j} * \exp (c_{2j} * PCR) \qquad 5.4.3$$

where X_j = Ratio of actual to predicted cost for duration range j

c_{1j}, c_{2j} = Parameters of the exponential expression for each duration range j

exp = Exponential

PRC = Accumulated proportion of repairs

Using this equation the values of the parameters, c_{1j} and c_{2j}, that determined the best fit of the cost ratio to the accumulated percent of repairs for each range of durations was calculated. These values are shown in Table C.6 of Appendix C.

Implementation In the Repair Model

The results of the preceding analysis of repair cost were implemented into the model in the following manner. First, an estimated cost of repair based upon the repair duration is calculated using equation 5.4.1 where b = .5 and DUR_i = Duration of repair i as predicted using procedures developed in section 5.3. Next this estimate of repair cost is modified by a random factor to simulate the distribution of repair cost for repairs of similar durations. This is done by substituting a uniformly distributed random number (RN) between 0 and 1 for PCR in equation 5.4.3 and using the parameters c_{1j} and c_{2j} for the appropriate range of j.

Finally, the cost of an individual repair is calculated as shown in equation 5.4.4.

$$COST = X_j * COST_i \qquad 5.4.4$$

where $COST$ = Estimated cost of an individual repair

$COST_i$ = Estimated cost of repair with a given duration

X_j = Estimated ratio of actual to predicted cost

It was desired that total cost be divided into labor and part cost. Therefore the actual labor and parts cost for repairs in each range of duration was analyzed. The proportion of cost which was labor (PLB) was fairly constant between .26 and .33 for most of the ranges. Therefore, the average value over all of the ranges was used, PLB = .27. Since it was desired in the model that the affects of changes in labor cost for repair be analyzed, a factor for changing labor cost (RLC) was included. Also, labor costs were expected to be affected by yearly wage inflation rates, so wage inflation was also included. Equation 5.4.5 is the equation used in the model to calculate labor cost.

$$CLB = PLB * COST * WAGEIFL \qquad 5.4.5$$

where CLB = Labor cost of repair

PLB = Proportion of total repair cost which is labor

WAGEIFL = Wage inflation accumulated for each year of the simulation

The parts' cost of repairs is calculated similarly. One difference, however, is that the parts' cost of repair is assumed to be related to the initial price of the tractor. This is done since a literature review indicated most repair costs are specified in terms of initial purchase price (ASAE Year Book, 1972). Since it was desired in the model that the effects of changes in parts' cost for repairs be analyzed, a factor for changing part cost was included in the model. Inflation in the purchase prices of spare parts (MCHIFL) also was included in the model. Equation 5.4.6 is used to calculate repair parts' cost in the model.

$$CPT = (1-PLB) * COST * MCHIFL * INTPRC/BASPRC \qquad 5.4.6$$

where CPT = Cost of repair parts

PLB = Proportion of total cost which is labor

COST = Total cost predicted by equation 5.4.5

MCHIFL = Inflation in machine parts

INTPRC = Initial purchase price of the tractor

BASPRC = Purchase price of tractors used at Comilla on which the coefficients of the model are based

The repair cost of each tractor during a season is then given by equation 5.4.7.

$$TRRPCT_{ij} = \sum_{n=1}^{k_{ij}} (CLB_{ijn} + CPT_{ijn}) \qquad 5.4.7$$

where $TRRPCT_{ij}$ = Repair of tractor i in season j

k_{ij} = Number of repairs occurring to tractor i in season j

CLB_{ijn} = Labor cost of repair n made on tractor i during season j

CPT_{ijn} = Part cost of repair n made on tractor i during season j

This concludes the description of the repair cost model used in the tractor hire service simulation.

Repair Cost Model Validation

As with previous models the repair cost model is verified by comparing the actual values with the mean of the predicted values. For the purpose of validation the repair cost model, the actual duration of each repair was used in equation 5.4.4 to predict repair cost. The total cost of the predicted and actual repairs in each range of duration is shown in Table 5.6. The standard deviation and the distance the actual cost is from the mean of the predicted cost as expressed in standard deviations is also shown in Table 5.6. This table shows that the model is quite accurate in predicting repair costs within each range of repair durations. Only for durations in the 6-10 day range was the actual cost more than one standard deviation from the predicted cost. The total accumulated cost for all ranges was also within one standard deviation of the predicted cost. Thus, the model appears to be a valid predictor of repair cost and has been accepted for application in the tractor hire service simulation.

Table 5.6 Actual Cost and Cost Predicted by the Repair Cost Model Based on Actual Repair Duration for MF 35 Tractors

Duration Ranges, days	Total Actual Cost Rs.	Predicted Cost Rs.	Std dev Rs.	No. std dev actual is from predicted
< 2	4063.42	4511.56	505.72	1
3 - 5	5756.81	6029.98	724.60	1
6 - 10	6505.91	7456.25	781.65	2
11 - 20	7530.00	7077.21	814.60	1
21 - 50	9274.82	8564.97	1688.08	1
51 - 100	5738.56	4876.20	2554.00	1
> 100	35,895.52	35,670.76	8110.00	1
Total	79,062.04	74,186.94	9721.50	1

5.5 REPAIR REMOVAL

The procedure used to assign tractors to repair was previously discussed. The following is the procedure for removing tractors from repair. The repair removal portion of the program subtracts one day from the duration of the repair on each day simulated. If after this day is subtracted, the duration equals zero, the repair has been completed and the tractor is removed from the array of tractors under repair (ITRR) and returned to the array of tractors available for work (ITRW). Then the number of tractors available for work is increased by one. But if after this day is subtracted, the duration is larger than zero, the repair is not completed and the tractor stays in the array of tractors under repair (ITRR).

The tractor when it is removed from repair is assigned an implement of the same type as the implement which was on this tractor prior to its breakdown. If this type of implement is not available, the tractor is equipped with the other type of tillage implement. The above procedure is repeated for each tractor under repair for each day of the simulation.

CHAPTER 6

6.0 INTRODUCTION

In this chapter the portions of the tractor hire service model which were developed and verified earlier in the dissertation have been combined and used to evaluate several aspects of tractor hire services. It should be emphasized that, although the model was developed from the farmer survey and the operations records of the Comilla cooperative tractor hire service, the model is intended to evaluate tractor hire services for developing countries in general and not to evaluate this specific tractor hire service as it existed in Comilla. Since the model is run as a tillage service only and no use of tractors for non-tillage activities is provided for in the model, cost comparison between the Comilla tractor hire service and the model are not possible. It is assumed, however, that the model does validly represent the expected operation of a tractor hire service, such as existed at Comilla, when the tractors of such a service are used only to perform tillage demanded by primary farmer cooperative organizations.

A small amount of the possible analysis capability of the model is presented here. It is hoped, however, that the analysis of tractor hire services included in this chapter can provide some insight into the operation of tractor hire services for developing countries.

6.1 TRACTOR NUMBER EFFECT ON HIRE SERVICE OPERATIONS

The amount and distribution of demand for tillage services is an important consideration in evaluating any mechanization program. Unless otherwise specified, a 15-year sequence of demand for tillage, based upon the tillage demand in Comilla, Bangladesh in 1969, but including a random variation in demand from one year to the next, is used throughout this chapter. The amount and distribution of tillage each season over the 15 years is retained from one run of the model to the next. This allows each change in the mechanization program to be evaluated based upon the same quantity and distribution of seasonal demand. The expected demand each season as predicted by 100 iterations of the model is shown in Figure 6.1.

Tractor Number Effect on Demand Delay

An important consideration for cooperative tractor hire services and government tractor hire centers is the number of tractors and equipment which they need in order to provide a timely and economic tillage service to farmers. The simulation model provides insight into this question. Figures 6.2 through 6.6 show the percent of demand delayed each season when the model was run with from 0 to 16 tractors in the tractor hire service. Delays in performing demand of 1, 3, 7, and 10 days are included in each figure. The model indicates, as shown by Figures 6.2 and 6.3, that over a narrow range, small changes in tractor numbers result in large changes in the percent of farmers who have their demand delayed for the various lengths of time. The demand for rotary tillage during the first demand period (Boro) shown in Figure 6.3, indicates, for example, that if the tractor hire service

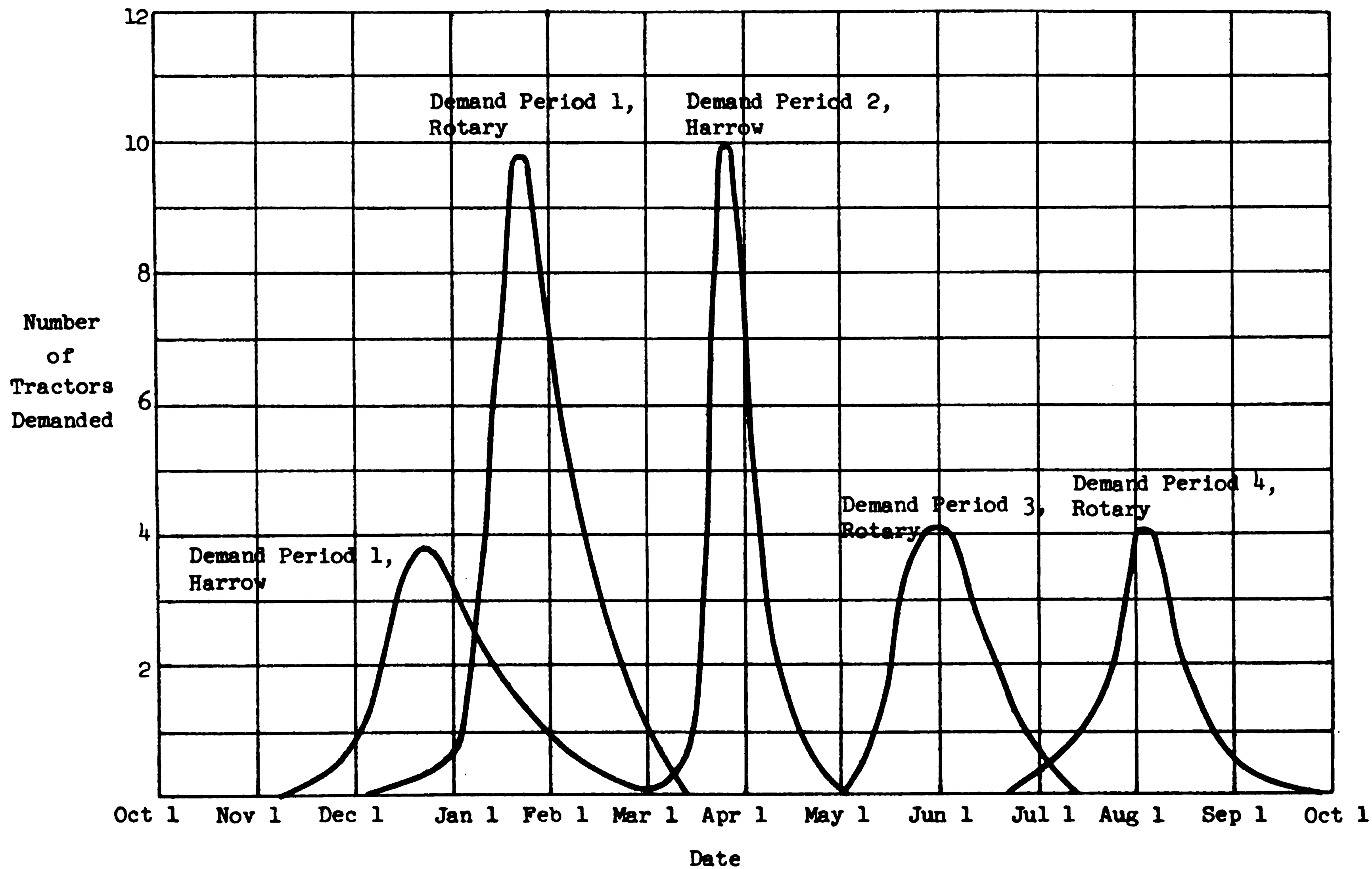


Figure 6.1 Expected Seasonal Demand for Tractors to Perform Tillage

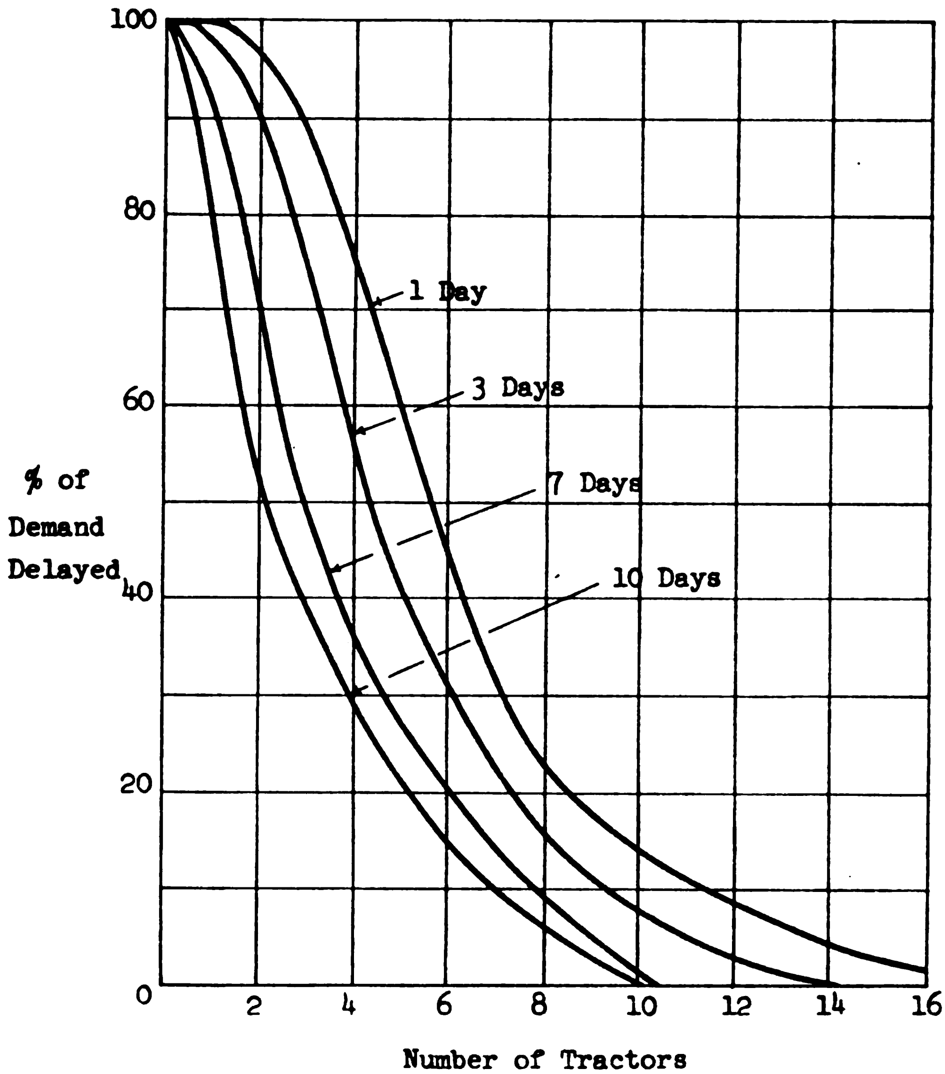


Figure 6.2 Delay in Performing Demand for Harrow Tillage During Demand Period 1.

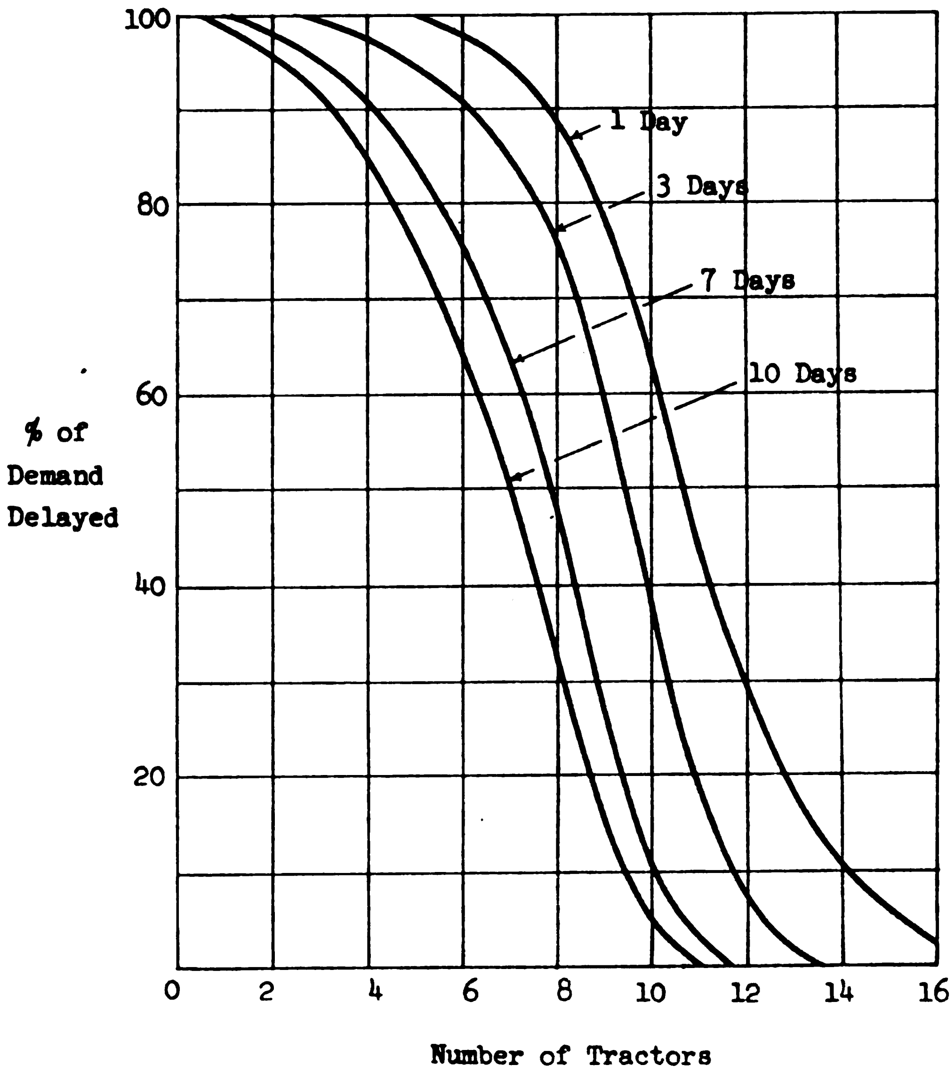


Figure 6.3 Delay in Performing Demand for Rotary Tillage During Demand Period 1.

owned eight tractors, 75% of the farmers would have at least a three-day delay in having their request for tillage filled and 30% would have in excess of ten days delay. If the tractor hire service increased the number of tractors from eight to ten, the number of farmers with a delay of three or more days would decrease to 35% and less than 5% would have delays over ten days. Similar narrow ranges are indicated for the other seasons. However, the number of tractors which effect these changes are different (see Figures 6.4 and 6.5). In the third demand period (Amon 1) shown in Figure 6.5 the largest decreases in delay occurred when going from four to six tractors and in the fourth demand period (Amon 2) as shown in Figure 6.6 when going from three to five tractors.

Tractor Number Effect On Demand Withdrawn

If there are delays in performing tillage for farmers, it must be assumed that some farmers will withdraw their requests. The model has been used to evaluate the effect of demand withdrawal for different numbers of tractors in the tractor hire service (Figure 6.7). The model indicates only a small change in the percent of total demand performed when demand is withdrawn after either two days delay or after 11 days delay. Substantial amounts of tillage are lost in either case, however, as the number of tractors in the tractor hire service is reduced. If a tractor hire service owned eight tractors, 91% of the demand would be performed if withdrawal occurred after two days delay and 96% if

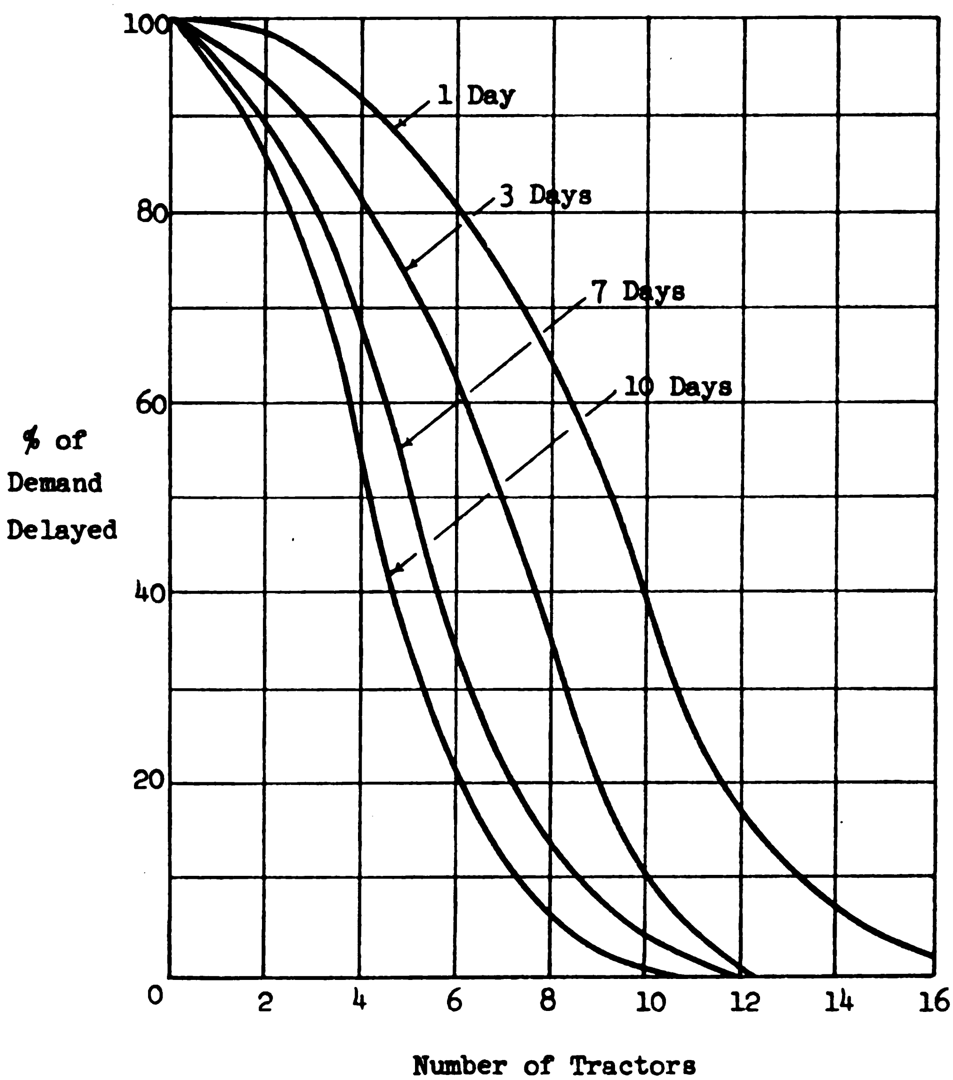


Figure 6.4 Delay in Performing Demand for Harrow Tillage During Demand Period 2

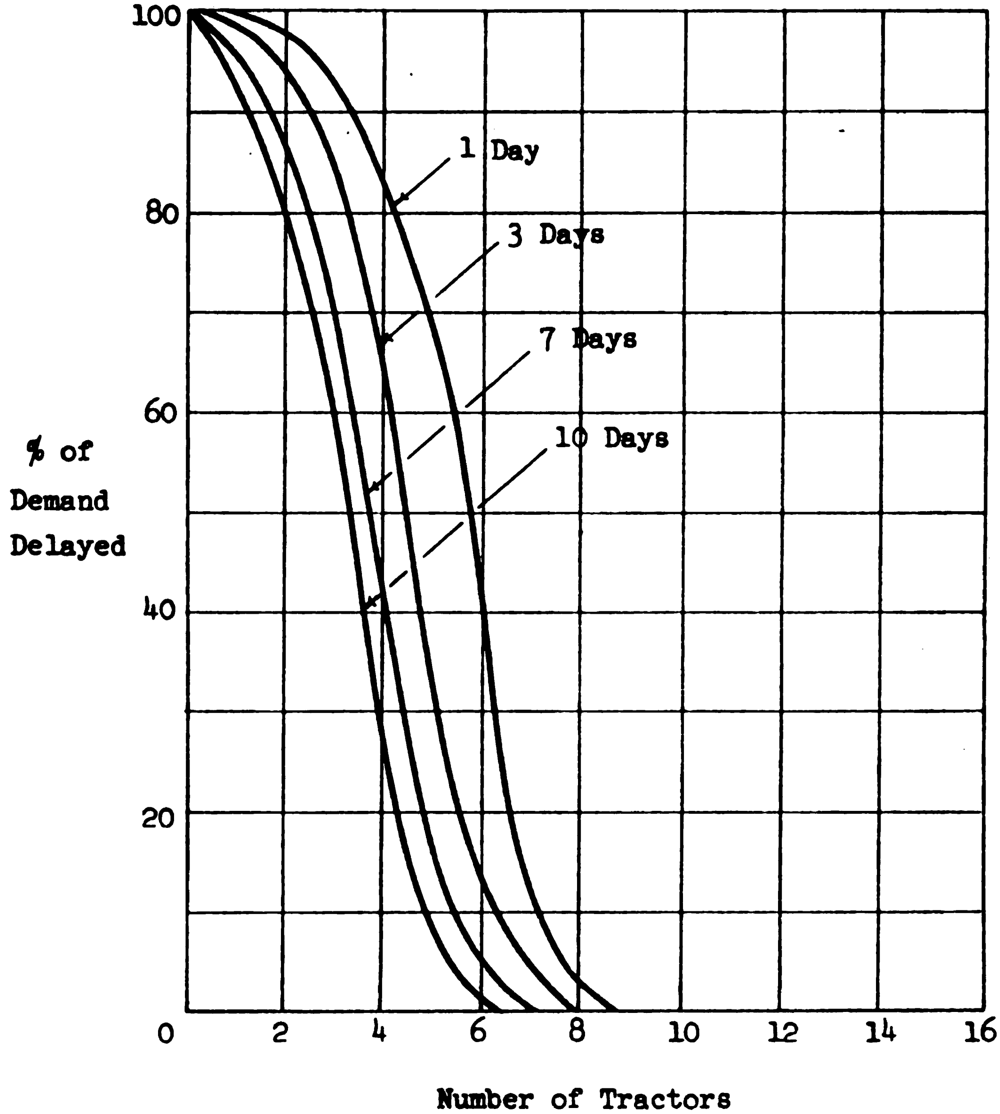


Figure 6.5 Delay in Performing Demand for Rotary Tillage During Demand Period 3

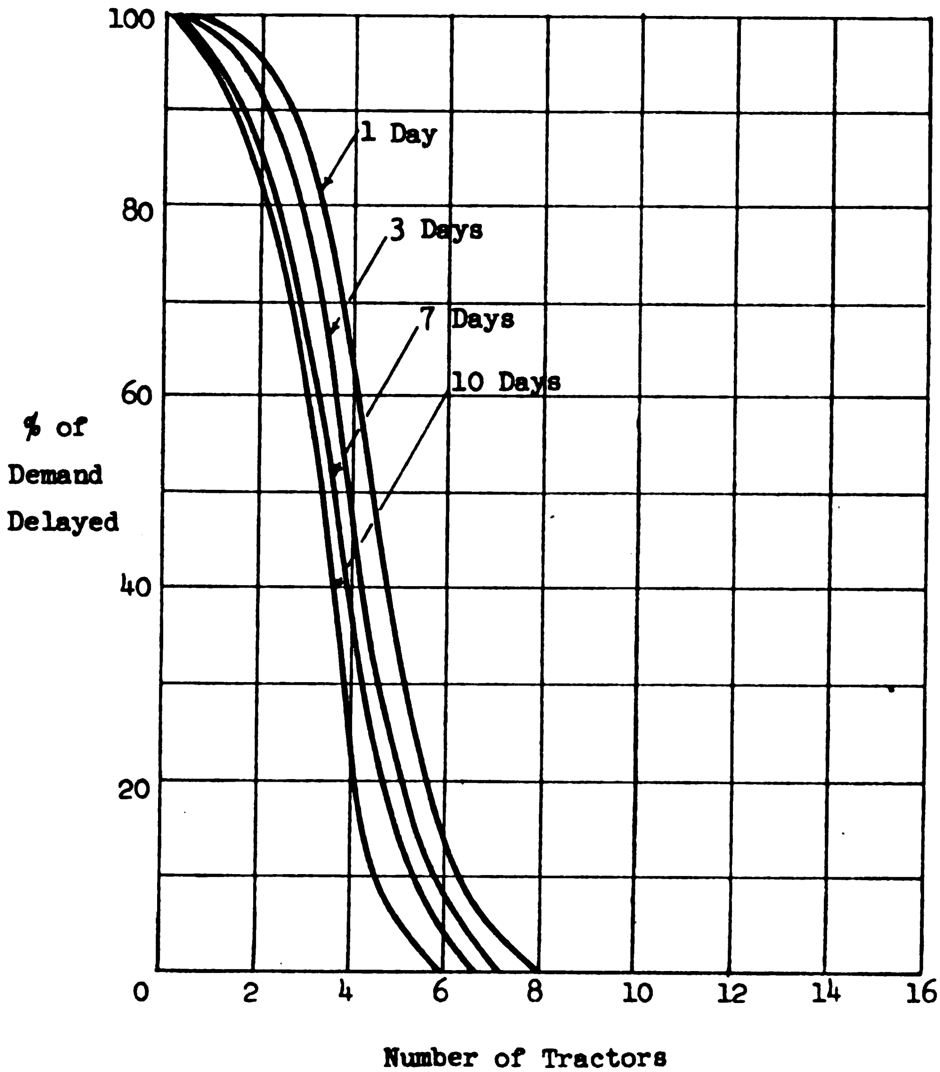


Figure 6.6 Delay in Performing Demand for Rotary Tillage During Demand Period 4

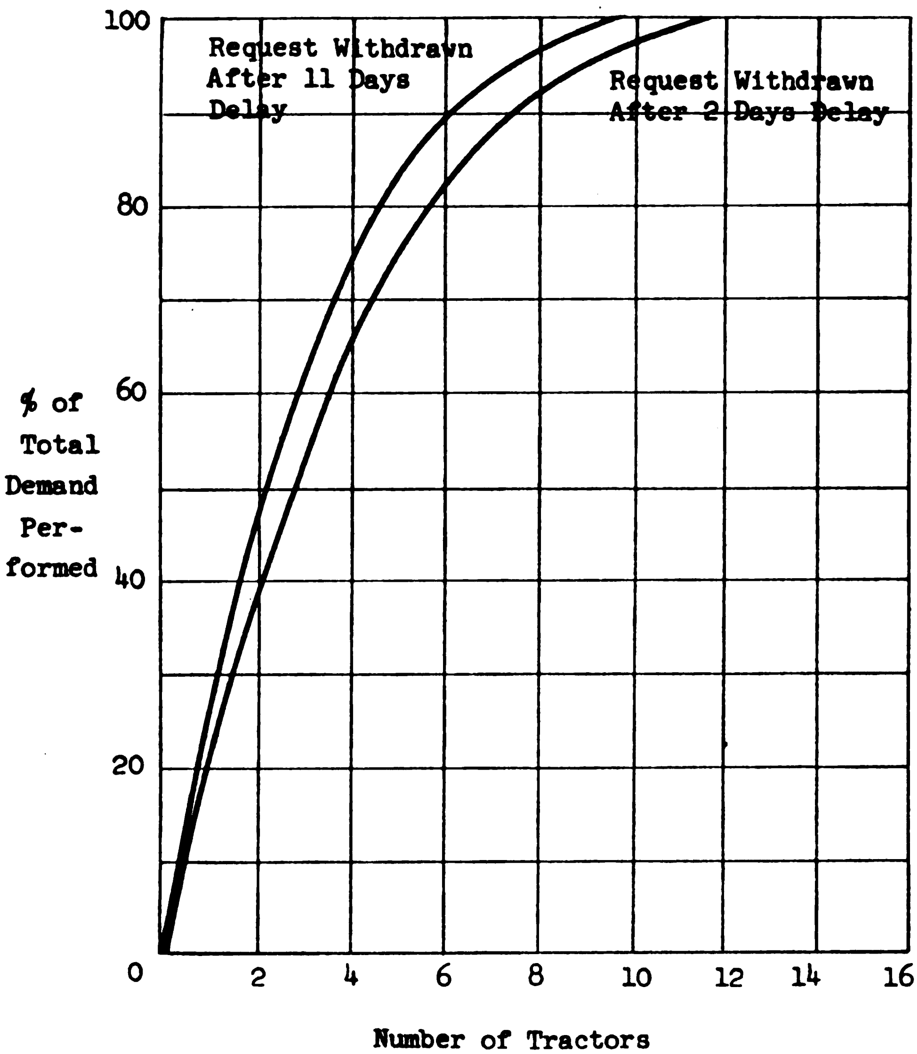


Figure 6.7 Demand Performed When Requests are Withdrawn Due to Delays

demand was withdrawn after 11 days delay. If the tractor hire service contained four tractors, only 63% of the tillage demand would be performed if demand was withdrawn after two days and it increased to 74% with withdrawal after 11 days.

Tractor Number Effect on Cost of Tillage

Since more tractors are needed in some seasons in order to provide a timely tillage service, it is desirable to investigate the tillage costs when various numbers of tractors are owned by a tractor station. The costs per acre of tillage as predicted by the model based upon the labor wage rate, fuel, and equipment prices in Bangladesh in 1969 are shown in Figure 6.8. Under these pricing conditions, costs would range from $3.65/acre ($9.00/ha) with four tractors in the tractor hire service to $6.00/acre ($14.80/ha) with 16 tractors. This figure also indicates that costs per acre increase at an increasing rate with additional tractors.

The lower cost with fewer tractors is the result of increased tractor utilization. With four tractors each tractor would till an average of 870 acres/year (350 hectare/year). With ten tractors this yearly rate would be reduced to 478 acres/tractor (197 ha/tractor). As can be seen in Figure 6.7, however, only 63 to 74% of the work demanded could be performed with four tractors, while ten tractors could perform 96 to 100% of the tillage demanded.

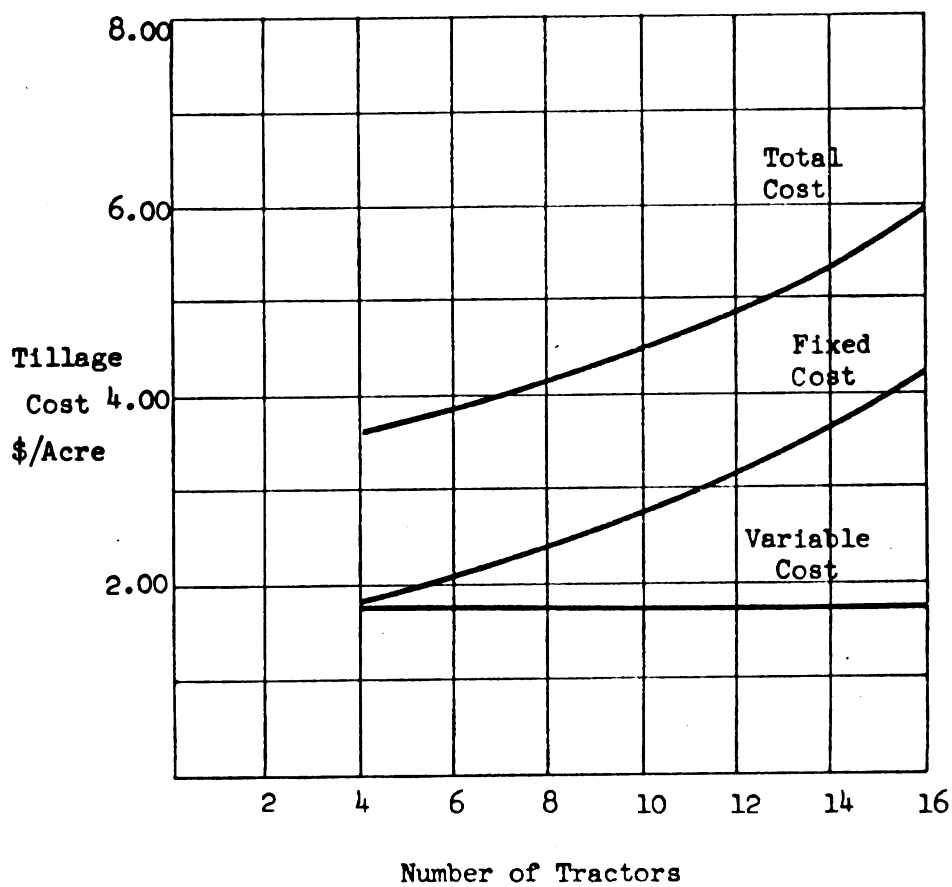


Figure 6.8 Tillage Cost for Different Numbers of Tractors

6.2 PLOT SIZE EFFECT ON TRACTOR HIRE SERVICE OPERATION

The method of determining tillage capacity based upon plot size was explained in Chapter 3. This method of determining tillage capacity allows the model to evaluate changes in plot size. Tillage capacity as a function of plot size is shown in Figure 6.9.

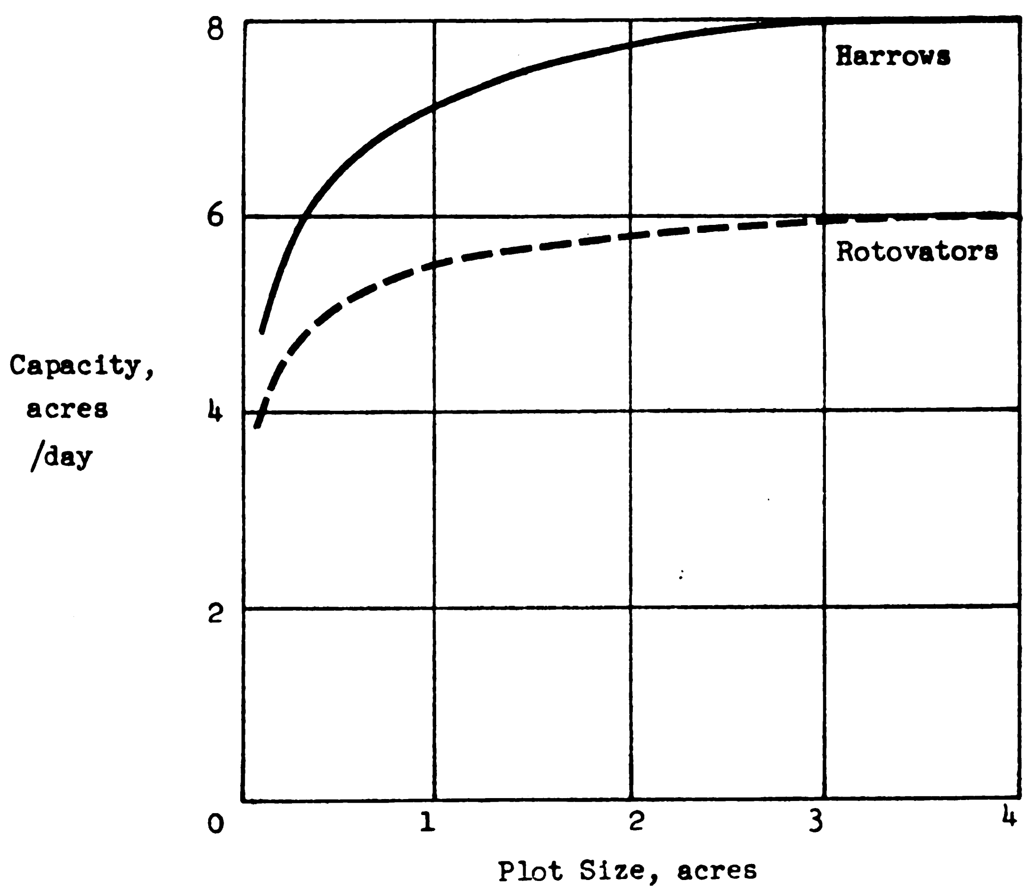


Figure 6.9 Plot Size Effect on Tillage Capacity

This figure shows that below about .3 acres (.12 ha), capacity of the tractor and implement of the size used in Comilla begins to decrease rapidly. Since in the Comilla Thana, the tractors are rented to farmer cooperatives on a daily basis, the cost to the farmer is in general inversely proportional to the tillage capacity. Tillage costs to the farmer would increase rapidly as plot sizes decrease below about .3 acres (.12 ha). For example, at a charge of $30.00 per day to the cooperatives the cost of rotary tillage would be $6.40/acre if plot sizes were .1 acre as compared to $5.00/acre if plot sizes were .3 acre. This is a 28% increase as plot size goes from .3 down to .1 acre.

A second consideration is necessary, however, and this is the cost of operating the tractor hire service as plot size decreases. To test this the model was run for 15 years based upon the tillage demand in Comilla for 1969 and with ten tractors in the tractor hire service. The average cost of the tractor hire service when plot size was .1 acre was $6.14/acre while the average cost when plot size was .3 acre was $5.76/acre. Thus, the tractor hire service cost was increased only 7% in the model when plot size decreases for .3 to .1 acre. The major reason for this small increase in total cost is the large fixed cost associated with a tractor hire service. The increased cost directly related to tillage capacity, such as fuel cost and field allowances, are small in relation to the fixed cost.

Based upon the preceding discussion, the conclusion can be made that as long as farmers are charged a fixed rate per day, the farmers with small plot sizes will be required to pay more per acre for tillage than will farmers with larger plot sizes. Therefore, charging on the basis of acreage rather than on a daily basis would seem to be more equitable for the farmers with small plot sizes.

6.3 TRACTOR SIZE EFFECTS ON TRACTOR HIRE SERVICE OPERATION

Selecting the appropriate size of tractor for a tractor hire service is difficult. However the simulation model can provide some insights into this problem. The program was run with three sizes of tractors, a 17.5 horsepower size, a 35 horsepower size, and a 70 horsepower size. The program was run with a .3 acre (.12 ha) and a .1 acre (.04 ha) plot size for each size of tractor. The total tractor horsepower in the tractor hire service was held constant at 350 horsepower when the sizes of tractors were changed. Thus, the tractor hire service was run with five 70 horsepower tractors, ten 35 horsepower tractors, and twenty 17.5 horsepower tractors. Both the size of the equipment and its purchase price was proportional to tractor horsepower. Thus, the initial investment was the same for all three tractor sizes. The number of personnel in the tractor hire service, however, was directly related to the number of tractors, since two tractor drivers are used for each tractor.

The costs of tillage as predicted by the model for different tractor sizes is shown in Figure 6.10. As can be seen from Figure 6.10, variable cost increases at an increasing rate as tractor size becomes

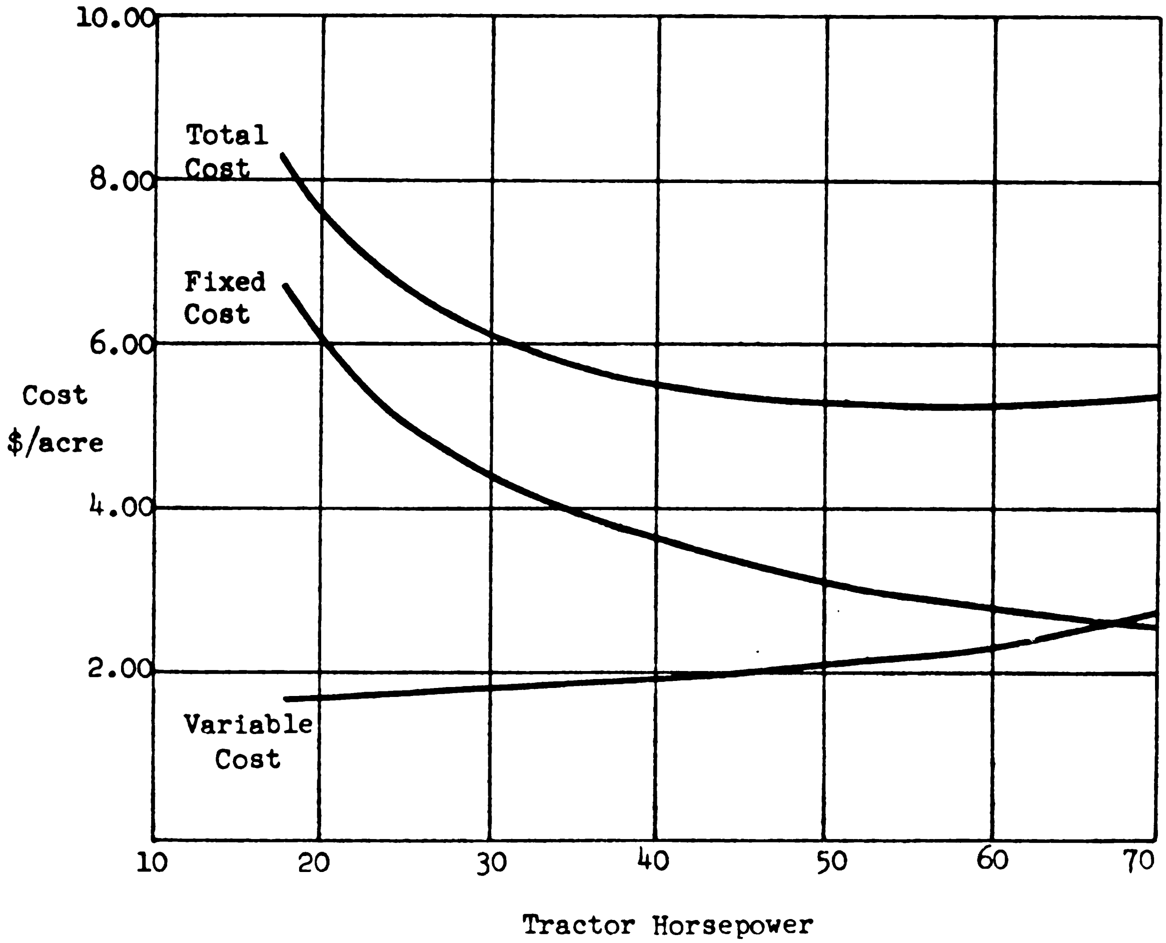


Figure 6.10 Tractor Hire Service Cost/Acre as a Function of Tractor Size

larger. This happens because with a fixed plot size a smaller tractor tills the field more efficiently. Fixed cost is also shown in Figure 6.10. As can be seen from the shape of this curve, fixed cost increases at an increasing rate as tractor size decreases. Since the fixed cost for small tractor sizes, those under 30 horsepower, is much larger than for tractor sizes larger than 30 horsepower, the total cost of tillage is much higher with smaller tractor sizes. It should be noted in Figure 6.10, that the total cost of tillage with the 35 horsepower tractors and the 70 horsepower tractors are almost the same. The cost with the 35 horsepower tractors was $5.76/acre while the cost with the 70 horsepower tractors was $5.34/acre.

The variable cost which is mainly made up of repair cost and fuel and lubricant costs was based upon 1969-70 fuel prices which in Bangladesh were about $.57 per gallon. With the present increases in import prices of both spare parts and fuel it appeared desirable to evaluate the effect of increased variable cost on the cost of tractor operation. Figure 6.11 shows the effect of doubling variable costs.

Figure 6.11 shows that with a doubling of the variable cost the 17.5 horsepower tractor still has the highest total cost per acre. However, the 70 horsepower tractors no longer had the lowest total cost per acre. For the costs illustrated by Figure 6.11, an intermediate tractor size between 30 and 50 horsepower would seem to have the least total cost per acre.

The expected loss of demand due to delay in performing the tillage for the different tractor sizes is shown in Figure 6.12. This figure shows that loss of demand increased nearly linearly with increasing tractor size for both the .3 and .1 acre plot sizes. Also, the demand lost for all tractor sizes increased as plot size decreased. Based

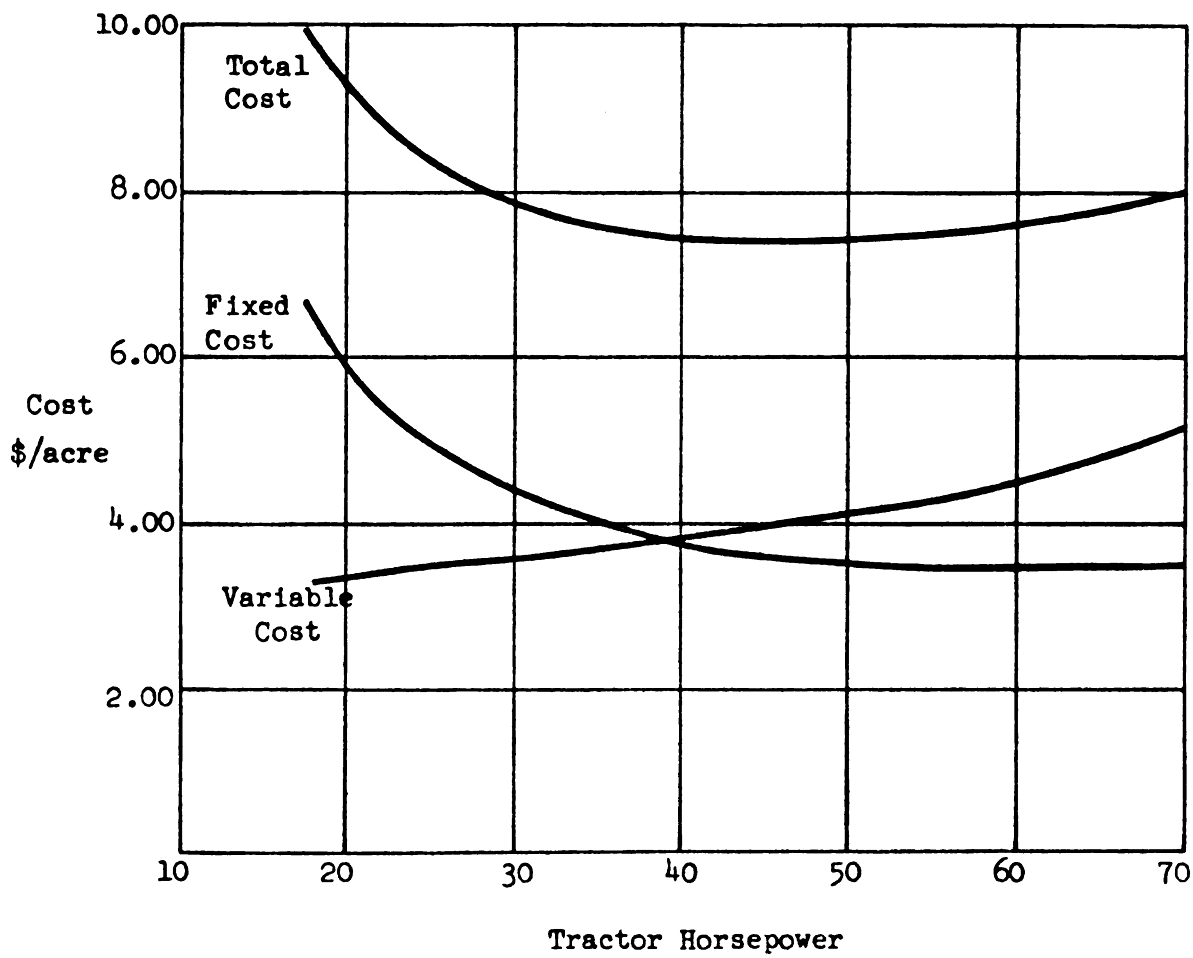


Figure 6.11 Tractor Hire Service Cost/Acre as a Function of Tractor Size With Variable Cost Doubled

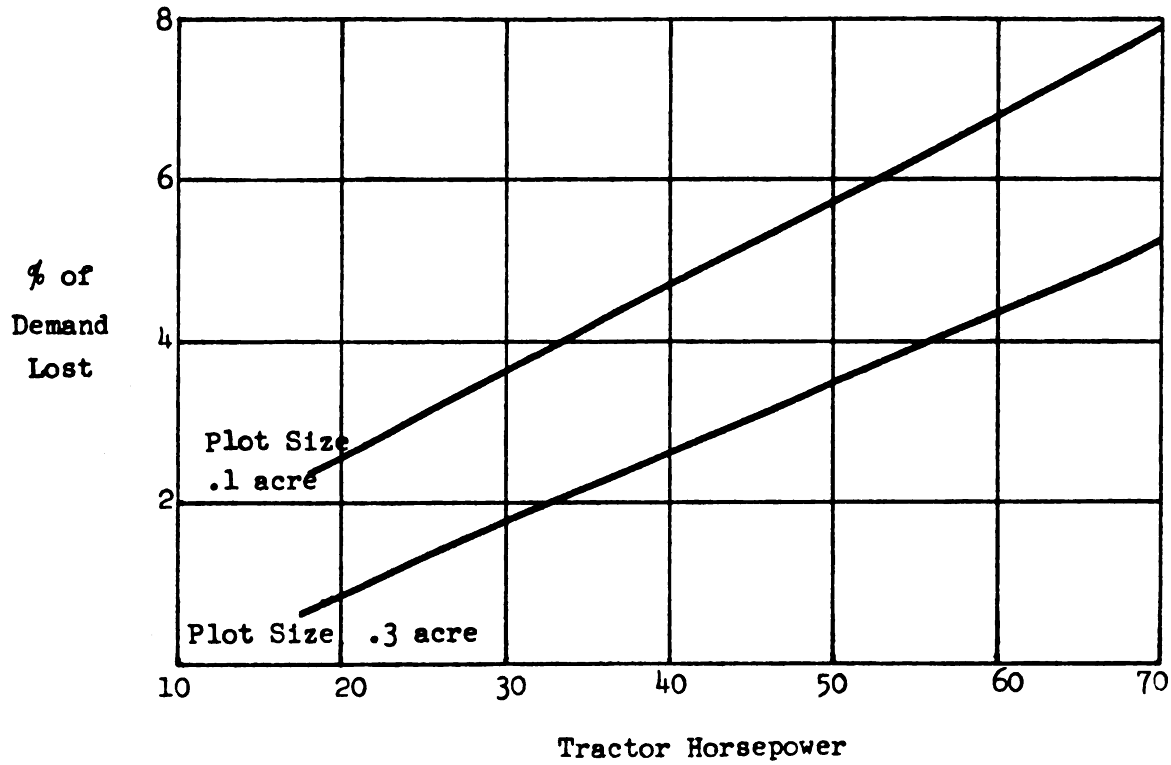


Figure 6.12 Demand Lost as a Function of Tractor Horsepower

upon Figure 6.12 the conclusion can be made that given a fixed total horsepower, a larger proportion of demand can be met with a large number of small horsepower tractors than by a small number of large horsepower tractors. One reason for this is that smaller tractors have a higher field efficiency for a given plot size than do larger tractors. Thus, they have a higher tillage capacity per horsepower than larger tractors.

Based upon the results of the model reported on in this section, it appears that small tractors are desirable from the standpoint of the percent of total demand they can be expected to perform. However, because of the large fixed cost, the total cost of tillage/acre with small tractors in the 15-20 horsepower range appears to be excessive when compared to larger tractors. On the other hand large tractors in the 50 and higher horsepower range also appear to be inappropriate for two reasons. First, they have higher demand losses than do smaller tractors. Second, with the expected increases in variable cost as the result of increased import prices the larger tractor would have a higher total operating cost per acre than would medium size tractors.

Thus, based upon the conditions under which the model was operated in this section, tractors in the 30 to 45 horsepower range appear to be the most appropriate.

6.4 EFFECT OF BREAKDOWN PROBABILITY AND REPAIR DURATION ON TRACTOR HIRE SERVICE

In Chapter 5 the cause of breakdowns was discussed. The hypothesis was made that if training programs for tractor operators and mechanics were developed, and if the quality of fuels and lubricants were improved, then the probability of breakdowns could be reduced. In this section the effect on tractor hire services as the result of a change in the probability of breakdowns is discussed. Table 6.1 shows the change in cost and demand lost as probability of repair is varied.

Table 6.1 Effect of Changes in Breakdown Probability On Costs and Demand Losses

Reduction in Probability %	Fixed Cost $/acre	Variable Cost $/acre	Total Cost $/acre	Demand Lost %
Major Breakdown				
-40%	3.92	1.69	5.61	.9
-20%	3.95	1.72	5.68	1.6
0	3.95	1.82	5.77	2.2
+20%	3.98	1.97	5.95	2.4
Field Breakdown				
-50%	3.93	1.74	5.68	.3

For this analysis the program was run to simulate 15 years with 10 tractors in the tractor hire service. Table 6.1 shows that changing the probability of repair has essentially no effect on fixed cost. There is some effect on variable cost as the probability is reduced. For example, when the probability is reduced 40%, variable cost per acre could be expected to go from $1.82 per acre down to $1.69 per acre which is a 7% reduction. However, a 40% reduction in breakdown probability reduces total cost per acre less than 3%.

The model as it was run for this analysis predicted a demand for tractors to till about 4800 acres/year. Multiplying the estimated saving per acre of $.13, times this acreage gives a total yearly saving, if breakdown probability could be reduced 40%, of $625.00. Thus, the model as it was operated for this analysis indicates that extensive training programs cannot be justified on the basis of reducing the probability of breakdowns.

The effect reducing breakdown probability has on the expected amount of demand loss is also shown in Table 6.1. Reducing the probability of a major breakdown by 40% reduces the demand which can be expected to be lost from 2.2% to .9%. The surprising result, however, is the effect reducing field breakdown probability has on demand lost. Reducing field breakdown probability reduces the expected loss in demand from 2.2% to .3%. Since field repairs are of only one day duration, intuition would seem to indicate that they should not have much effect upon demand losses. However, with the model as it was run for this analysis, field breakdowns in combination with longer repairs apparently are a major determining factor in demand loss.

Repair Duration Effect on Tractor Hire Service

In Chapter 5 the long duration of some repairs was discussed. These long repair durations were usually caused by the lack of the necessary repair parts and the need to have them imported. If an adequate store of spare parts was maintained in the developing country, it is assumed that repair durations could be substantially reduced.

The effect of changes in repair duration is shown in Table 6.2. This table shows that a reduction in repair durations does increase the effectiveness of the tractor hire service. The model estimated that

Table 6.2 Effect of Changes in Repair Duration on Costs and Demand Losses

Repair Duration Reduction %	Fixed Cost $/acre	Variable Cost $/acre	Total Cost $/acre	Demand Lost %
-50%	3.93	1.83	5.76	.8
-25%	3.96	1.81	5.77	2.0
0	3.96	1.81	5.77	2.2
+25%	4.04	1.79	5.83	3.7

demand losses would be reduced from 2.2% to .8% if the repair duration was cut in half. Since it was assumed that repair cost would not be affected by reducing repair duration, the cost of tractor tillage was not significantly changed by reducing the repair duration.

6.5 TRACTOR REPLACEMENT TIME AND WORKING HOURS EFFECT ON TRACTOR HIRE SERVICE

The time of replacement is an important consideration in the effective operation of a tractor hire service. If tractors and equipment are retained in a tractor hire service too long both the cost of tillage and the timely performance of demand may be adversely affected. Since depreciation costs for tractors are assumed to be directly proportional to tractor use, fixed cost remains constant over the range of replacement time used in the present analysis. Variable cost and the operating effectiveness are therefore the determining factors needed to estimate an appropriate replacement time. Figure 6.13 shows variable cost as a function of replacement time.

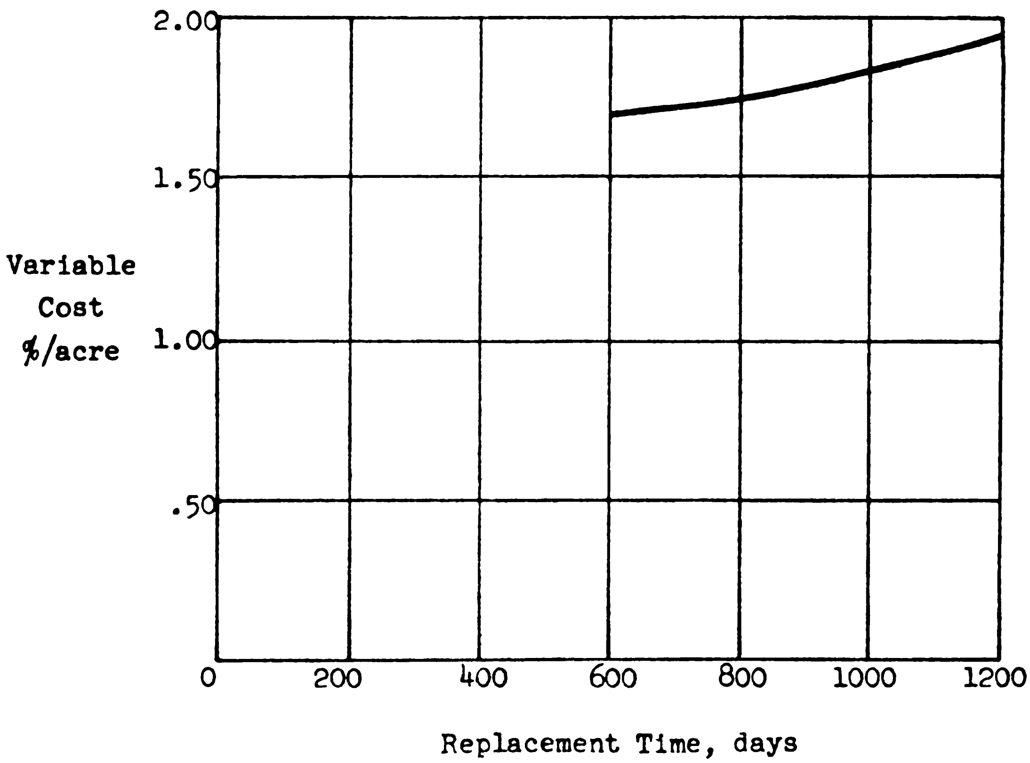


Figure 6.13 Variable Cost as a Function of Replacement Time

Figure 6.13 shows that over the range of tractor replacement times considered, the variable cost is increasing at an increasing rate. However, the variable cost even at 1200 days of tractor operation does not appear to justify tractor replacement.

The demand losses as a function of tractor replacement time are shown in Figure 6.14.

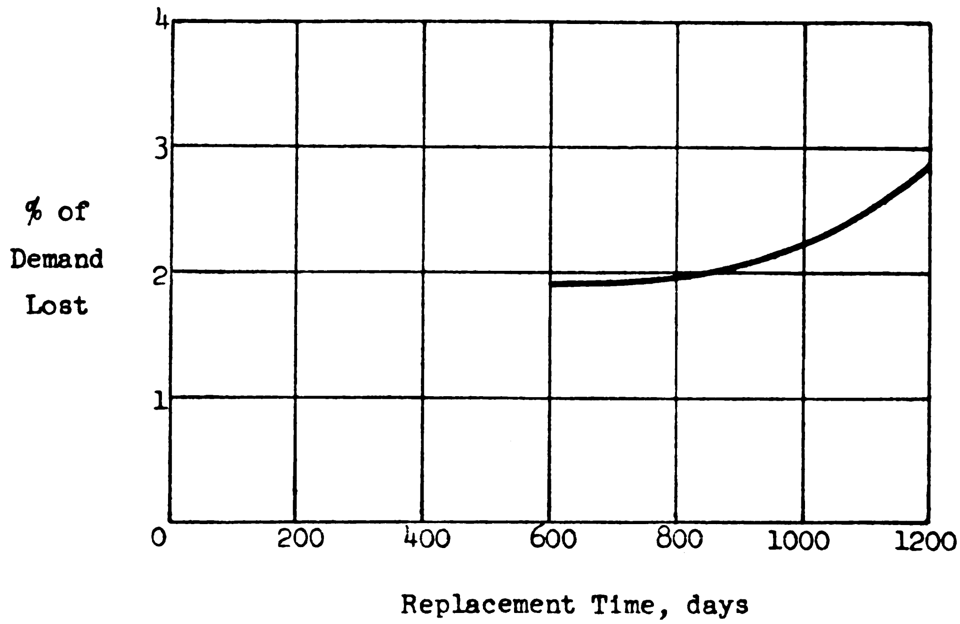


Figure 6.14 Loss in Demand as a Function of Replacement Time

Figure 6.14 shows that the percent of demand which is lost increases at an increasing rate for longer replacement times. Even with replacement at 1200 days, however, the losses had not exceeded 3% of the total demand. Therefore, replacement does not yet seem to be justified at 1200 hours of use. It is anticipated, however, that with the rate of increase in demand loss at 1200 hours, replacement would soon be justified.

Working Hours Per Day Effect on Tractor Hire Service

In most tractor hire services working hours are established and deviations are seldom made from these hours. This is because most tractor drivers and management personnel prefer to work set hours. During a period when demand for tractor service is low, a policy of fixed working hours is adequate. However, when demand for tractor hire service exceeds the capacity of the existing number of tractors to perform this tillage then increasing the hours the tractors work can increase the effectiveness of the tractor hire service operation. For example, when the model was run over a 15 year period with ten tractors in the tractor hire service, the demand lost due to excessive delay was predicted to be 6% if the tractors operated eight hours per day and decreased to 2.2% if the tractors operated 10 hours per day. If tractor operation hours were increased above 10 hours, it could be expected that demand losses could be reduced to zero.

6.6 EFFECT OF WORLD PRICES ON TRACTOR HIRE SERVICE

In the preceding sections, the discussion has dealt mainly with tractor hire service operation at the price levels of 1969-70. In this section the possible effect on tractor hire services of the recent changes in world prices for fuels and machinery is discussed.

With increased international prices for fuels, machines, and spare parts, the use of tractors for non-essential agricultural purposes should be carefully evaluated. It should be emphasized that over several years the foreign exchange requirement of a tractor hire service would be approximately the same irregardless of the number of tractors. This is because in most developing countries depreciation of equipment is usually directly related to usage and equipment most often does not become obsolete before it has worn out. In Figure 6.8, shown in section 6.1, increased costs with larger numbers of tractors were mainly due to increased personnel hired to operate and maintain the machines. In Ccmilla there were two drivers for each tractor and one maintenance person for every four tractors. These persons were paid a fixed salary whether the tractors worked or not. Since it is socially unacceptable to lay off personnel during slack periods, labor costs continue whether the tractors work or not. Thus, a reduction in the cost per unit of operation is possible only by increasing tractor utilization. This is often done by using tractors for non-agricultural purposes during the periods of the year when tractors are not fully utilized for tillage. Since this means that the tractors depreciate more quickly because of the additional work they must be replaced more often and this requires more foreign exchange, than would be required if tractors were used only for tillage.

The model has been used to predict the effects of price changes on the costs of operation for a tractor hire service with ten tractors. This is shown in Table 6.3. The model indicates that for each 10% increase in fuel prices, variable costs/acre increase 4.6% and total

Table 6.3 Cost Increases for Tractor Tillage Due to Increases in Fuel Prices, Purchase Prices, Interest Rates, and Labor Costs

For Each 10% Increase in	% Increase In		
	Fixed Cost	Variable Cost	Total Cost
Fuel Price	0	4.6	1.8
Purchase Price	1.9	4.8	3.1
Interest Rate	1.8	0	1.1
Wage Rate	7.1	0	4.3

costs/acre increases 1.8%. Thus with the two to three fold increase in international prices of petroleum, the costs of tillage/acre could be increased from 36 to 54%. Purchase price for tractors, equipment, and repair parts was also predicted. For each 10% increase in purchase price, total cost will increase 3.1%. With a 30 to 50% increase in imported equipment and the increased fuel cost, it does not seem unreasonable that the foreign exchange requirements for agricultural mechanization programs could easily increase between 50 to 70%. Combined with domestic inflation, the cost of tractor hire services could rise even higher. Price rises such as these would appear to put agricultural mechanization programs including tractor hire services in jeopardy. However, world food prices have increased even faster. Thus, selective mechanization which increases agricultural production may still be justified.

Throughout this chapter the application of the model has been mainly limited to an evaluation of the cooperative type of tractor hire service. The model also has the capability to perform similar analysis on other types of tractor hire services, such as the contract tractor hire services. However, no attempt has been made to include them in this dissertation.

CHAPTER 7

7.0 INTRODUCTION

During the research study and thesis preparation the following items were accomplished:

1. A simulation model of tractor hire service operation was developed. The model included submodels for predicting demand for tillage and for predicting repair occurrence, duration, and cost.
2. An evaluation of the cooperative type of tractor hire services was made using the simulation model.
3. More than ten papers and articles were published based upon the results of the research performed at Comilla, Bangladesh.

7.1 CONCLUSIONS CONCERNING AGRICULTURAL DEVELOPMENT EFFORTS IN THE COMILLA THANA, BANGLADESH

1. Increased intensity of land use through mechanized irrigation is an important method of generating demand for hired labor in Bangladesh.
2. Cooperative members come mainly from farm sizes larger than one acre.
3. Mechanized methods of lifting water have almost completely replaced manual methods in the Comilla Thana.
4. Since the operation of tubewells and pumps is controlled by cooperative members, they are able to derive greater benefits

4. (cont) from the irrigation program and thus greater benefits from the improved varieties than non-members. Non-members' only method of obtaining water from mechanized irrigation is through purchase from the primary cooperatives. Cooperative members have been able to irrigate a larger proportion of their farm land than non-members.
5. The rate of adoption of improved rice varieties during the winter cropping season was very fast, requiring only five years for cooperative members to reach almost complete adoption and four years for non-members. The faster rate for non-members can be attributed to the demonstration effect of the cooperative members.
6. Use of improved rice was limited to three varieties through 1969. In 1970, however, additional improved varieties were introduced and used by cooperative members.
7. Yields for improved varieties were from two to three times larger than local varieties.
8. Cooperative members have continually obtained higher yields and invested more in the factors of production than non-members. The yield differences between cooperative members and non-members, however, has been less with improved varieties than it was with non-improved varieties. Thus, the improved varieties have tended to lessen the unequal distribution of benefits of winter irrigation between cooperative members and non-members.

9. Introduction of improved varieties has led to an increase in the use of both traditional and non-traditional production inputs for both cooperative members and non-members.
10. Farmers appeared to adopt improved varieties at about the same rate, regardless of farm size. Cooperative members, however, adopted before non-members.
11. Non-cooperative farmers with less than 1.0 acres (.4 ha) and the landless were the only groups who have consistently been represented in winter irrigation in a smaller proportion than they are in the total population.
12. Small farmers appear to be able to grow improved varieties as successfully as large farmers.
13. The planting, harvesting, and fertilization operations provide the majority of employment for hired labor.
14. Small scale mechanization with hand operated machines has been generating a demand for additional hired labor in the weeding and threshing operations.
15. Labor utilization in the application of insecticides is negligible and evaluation of mechanization in this operation should be based upon its effectiveness in insect control.
16. Mechanization of the tillage operation has not significantly displaced hired labor. It is of substantial benefit to the small land owners, especially those without animal power. It complements rather than displaces animals as a power source in the tillage operation.

7.2 CONCLUSIONS CONCERNING TYPES OF TRACTOR AND EQUIPMENT OWNERSHIP AND OPERATION

1. Private ownership of tractors and equipment in labor surplus countries has tended to displace rural landless laborers. It has also been unavailable to the bulk of the subsistence farmers in developing countries.
2. Group ownership of tractors and equipment has been successful when two to four farmers participate. It has not been demonstrated to be successful for a larger number of persons, unless there is a formal organization.
3. Private ownership with contract hiring has been successful in making agricultural mechanization available to a large number of people in several countries. Contract hire services, however, have generally not been available to the smaller farmers in developing countries.
4. Government tractor hire services have been found to be of benefit to small farmers and have not seemed to displace hired labor. These tractor hire services, however, have tended to be bureaucratic, inefficient, and very expensive to operate.
5. Cooperative tractor hire services have also been found to be of benefit to small farmers and have not displaced hired labor. They have tended to be less bureaucratic, and less expensive to operate than government tractor hire services.

7.3 CONCLUSIONS BASED UPON THE RESULTS OF THE SIMULATION MODEL

1. Over a narrow range, small decreases in the number of tractors in a tractor hire service results in large increases in the percent of farmers who have their demand delayed for various lengths of time.
2. The capacity of tractors and implements does not begin to decrease rapidly until plot size drops below .3 acre (.12 ha) for tractors in the 35 hp size range.
3. With field sizes of from .1 to .3 acres (.04 to .12 ha) an intermediate size tractor of 30 to 45 horsepower would appear to be the most appropriate for tractor hire services.
4. When demand for tractor hire services exceeds the capacity of the existing number of tractors to perform this tillage, then increasing the hours the tractors work per day can increase the effectiveness of the tractor hire service operation.
5. Given a fixed total horsepower (a) a larger proportion of demand can be met with a large number of small horsepower tractors than by a small number of large horsepower tractors, (b) fixed cost increases at an increasing rate as tractor numbers increase, and (c) variable cost increases at an increasing rate as tractor numbers decrease. The least costly tractor hire service may then occur with medium size tractors.
6. In tractor hire services where personnel are full time employees, the fixed cost of tractor operation may be more than the variable cost.

7. With the two to three fold increase in international prices of petroleum, the cost of tillage per acre can be expected to increase 36 to 54%.

7.4 RECOMMENDATIONS FOR ADDITIONAL RESEARCH

The research study resulting in this dissertation attempted to apply the concepts of agricultural engineering and systems analysis to the agricultural mechanization experience of Comilla, Bangladesh. This research study was fairly narrow in scope in comparison to the broad and critical problems facing agricultural modernization in many developing countries. Some of the areas that require additional research and for which systems analysis appears to be appropriate are:

1. An analysis of the effect of rising fuel and equipment costs on the use of tractors and machinery in agricultural modernization programs in developing countries.
2. An analysis of mechanization in relation to labor employment in crop production in developing countries.
3. Investigations into the relationship between agricultural mechanization and production of various crops in developing countries to identify the selective mechanization requirements of these crops.
4. Research into the supporting services and trained personnel required for effective agricultural modernization in selected developing countries.

APPENDIX A

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APPENDIX A

DESCRIPTION OF THE COMILLA ACADEMY

The Comilla Academy for Rural Development was conceived initially by the government as a training center for public officials responsible for rural development programs. The primary objective of the Academy was to help the government officials put to more productive use the administrative and technical skills they already had and to aid them in the acquisition of new skills needed in rural development programs. The Academy was from the beginning a government institution concerned with public administration and the findings of the experimental-demonstration work of the Academy were made available directly and immediately to the government for policy and operational uses.

To test its experiments in local government and economic development, the Academy was allowed to use the hundred-square mile Comilla Thana in which it was located as a laboratory area for rural development. The Academy made the assumption that progress in rural modernization would depend initially on the willingness of villagers to try something new. Because of the extremely small land holdings and the lack of any apparent basis for establishing credit worthiness it was concluded that adoption of changes by scattered individuals would have little effect on development. Thus it was concluded that to achieve the benefits of modernization a number of farmers had to act together. For this reason, and because the village was a potent force in the control of behavior, the village was chosen as the unit through which modernization would be introduced.

In order to reach large numbers of villages quickly and economically, it was decided that those farmers in each village who chose to participate in the program would select one person to serve as the organizer for that village and he would receive weekly training at the Academy. The organizer acted as the intermediary between the village and the Academy. He was the fiscal agent who collected the savings of the individual villagers for deposit to the credit of the village group. Such deposits were used for investments in joint purchases, use of machinery and other centrally provided services. A model farmer was also selected for training at the Academy by each village group. He then demonstrated on his own land the improved farming techniques he had learned. The use of local persons as village organizers and model farmers utilized local resources and leadership to demonstrate improved farming practices. The weekly training of village organizers and model farmers involved collaboration between Academy staff, thana agricultural officers, and other government officers responsible for nation building. This collaboration led to the establishment of the Thana Training and Development Center which coordinated the various public and private development activities in the thana, especially the work of the thana council and the central cooperative association.

From the beginning the major tenets of cooperative organization were adopted and as village groups developed they were registered as cooperative societies. Weekly savings, credited to individual savers but aggregated in the name of the voluntary village group, created discipline and became the means of capital formation. This made it possible to rely upon village credit worthiness as collateral for loans and encouraged the villagers to agree upon joint planning for the use of tractors and irrigation pumps. Later a whole array of more sophisticated central services were developed based upon this collateral.

An early assumption of the Academy was that research, evaluation, training and extension could be integrated in a single educational institution concerned with rural development. The problems of the villagers were used as the basis for experimentation and research. The results of the experimental efforts were documented and used to develop new materials for the instruction of officiers and village leaders in the extension of validated practices. Throughout this process, village level research was the principal tool for documentation and evaluation.

The Comilla program involved both private cooperatives and government programs for development, and created administrative arrangements which constructively redefined the roles of government officials to the villages, to one another, and to wider concerns of government itself.

In summary, the Comilla Academy program placed heavy emphasis on economic and technological factors. The Academy was rigorous regarding its demands on participants, including sanctions for deviation from agreed-upon policies and procedures. It was very experimental using the laboratory area as a testing ground for ideas which might later be dropped or substantially modified before being advocated for adoption elsewhere. It was comprehensive with programs relating to food production, family planning, and community development. Finally, it provided for the involvement of both the private and public sectors in the whole rural development process. As a complement to their own staff the Academy effectively utilized Michigan State University advisors, Japanese experts, Peace Corps volunteers, British volunteers, and Afro-Asian scholars in research and training programs.

To support the village level groups who became registered as cooperative societies, a thana level central cooperative association was developed. This association, called the Kotwali Thana Central Cooperative Association (KTCCA), was developed to give support to the activities of the local cooperative societies and render services that could not be provided by individual societies. It was created 1) to promote the continuation and expansion of savings of members in cash and in kind, 2) to make provisions for crop-production loans and medium-term credit to the local cooperative societies for production purposes, 3) to provide training for the members and staff of the cooperatives, 4) to carry on bulk marketing and purchase activities, 5) to procure, maintain, and hire out useful farm machines to the primary societies, and 6) to establish a research and demonstration laboratory activity to yield practical operational information on cooperatives, farm machinery, and needed adjustments in the civil administration of the project area.

From the outset there was a close relationship between the organization of cooperatives and the use of farm machinery. To organize and administer the mechanization program with the central cooperative association, a cooperative machine shop and tractor station was set up. The organization and operation of this cooperative tractor hire service was the basis on which the simulation model and conclusions concerning cooperative tractor hire services discussed in this dissertation were based.

APPENDIX B

Table B.1 Initial Value of Variables in the Deterministic Demand Equation which are Constant for All Years

Identification	Seasons, k				Source of value
	k=1 Boro	k=2 Aus	k=3 Amon 1	k=4 Amon 2	
M_{11k}	.24	.065*	.07*	.07*	Crop cutting surveys
M_{12k}	.24	.065*	.02*	.02*	Crop cutting surveys
M_{21k}	.15	.065	.07	.07	Crop cutting surveys
M_{22k}	.15	.065	.02	.02	Crop cutting surveys
S_1	.25	.25	.25	.25	Crop cutting surveys
S_2	.20	.20	.20	.20	Crop cutting surveys
APC	--	--	90.0	90.0	PARD Annual reports
APM	--	2.26	--	--	Akhter, 1964
P_1	--	--	.65	--	Tillage demand records
P_2	--	--	.20	--	Tillage demand records
C_2	--	.85	--	--	Crop cutting surveys

* No improved rice varieties were used in these seasons at the time of the surveys were made. Values were assumed to be the same as for non-improved varieties.

Table B.2 Initial Value of Variables in the Deterministic Demand Equation which Vary with Time

Identification	Year				Source of value
	1966	1967	1968	1969	
n_1	29	63	128	193	PARD Annual Reports
n_2	129	162	133	108	PARD Annual Reports
A_{11}	45.	49.	41.	44.	PARD Annual Reports
A_{12}	15.	12.3	10.4	8.54	Crop Cutting surveys
MPC	32.	37	44.	38.	PARD Annual Reports
R_{11}	0	.31	.78	.86	Crop cutting surveys
R_{12}	0	0	0	0	Crop cutting surveys
R_{13}	0	0	0	0	Crop cutting surveys
R_{14}	0	0	0	0	Crop cutting surveys
R_{21}	1.00	.69	.22	.14	Crop cutting surveys
R_{22}	1.00	1.00	1.00	1.00	Crop cutting surveys
R_{23}	1.00	1.00	1.00	1.00	Crop cutting surveys
R_{24}	1.00	1.00	1.00	1.00	Crop cutting surveys
C_{11}	.85	.82	.95	.95	Crop cutting surveys
C_{12}	.57	.53	.43	.34	Crop cutting surveys

Table B.3 Values of the Variables Used in the Validation Test of the Delay Model for Predicting Tractor Demand

		Boro Harrow	Boro Rotary	Aus Harrow	Amon 1 Rotary	Amon 2 Rotary
1966	TI *	35	45	117	151	252
	DEL **	40	45	40	40	40
	K ***	4	10	20	5	10
1967	TI	55	55	117	166	247
	DEL	40	45	40	40	40
	K	4	10	20	5	10
1968	TI	25	45	107	176	247
	DEL	40	45	40	40	40
	K	4	10	20	5	10
1969	TI	20	45	107	176	237
	DEL	40	45	40	40	40
	K	4	10	20	5	10

* TI = the day in the simulation that the seasonal tillage demand is introduced into the delay process

** DEL = delay parameter

*** K = order of the delay

Note: $\frac{DEL}{K}$ = the delay in each individual stage of the delay

Table B.4 Autocorrelation Coefficients and Constants for Determining Variance for the Exponential Autocorrelation Subroutine

	XLMDA	a	b
Boro Harrow	.50	.70	.0040
Boro Rotary	.50	.50	.0023
Aus Harrow	.55	0	.011
Amon 1 Rotary	.45	.25	.0090
Amon 2 Rotary	.45	0	.0095

Table B.5 Expected and Actual Number of Days During the Boro Season on Which the Given Number of Tractor Days of Harrow Tillage were Demanded in the Comilla Thana

Demand Tractor-Days	Number of days on which given demand occurs											
	1966			1967			1968			1969		
	Act-ual	Pre-dict	Std dev	Act-ual	Pre-dict	Std dev	Act-ual	Pre-dict	Std dev	Act-ual	Pre-dict	Std dev
< 2	28	40.12	5.05	35	28.56	4.07	19	30.70	4.52	20	29.29	4.08
2 < 3	14	7.88	3.13	12	14.30	3.95	7	17.77	4.06	13	17.03	4.60
3 < 4	4	.38	.72	7	6.55	2.93	4	11.41	3.55	9	12.59	3.31
4 < 5	3	0	0	7	1.48	1.62	13	6.51	2.99	7	8.41	2.51
5 < 6				2	.01	.10	6	2.38	1.86	5	4.46	2.16
6 < 7							1	.15	.67	4	1.15	1.25
7 < 8										0	.02	.14

Table B.6 Expected and Actual Number of Days During the Boro Season on Which the Given Number of Tractor Days of Rotary Tillage were Demanded in the Comilla Thana

Demand Tractor-Days	Number of days on which given demand occurs											
	1966			1967			1968			1969		
	Act-ual	Pre-dict	Std dev	Act-ual	Pre-dict	Std dev	Act-ual	Pre-dict	Std dev	Act-ual	Pre-dict	Std dev
< 2	6	21.49	2.83	32	33.49	4.22	19	21.56	3.98	15	13.80	2.70
2 < 3				2	1.57	1.75	12	9.05	2.74	10	7.95	2.85
3 < 4							4	9.75	2.99	5	5.15	2.10
4 < 5							6	9.05	2.50	3	4.26	1.92
5 < 6							6	4.36	2.21	4	4.37	2.05
6 < 7							1	.69	.98	5	4.14	2.01
7 < 8							5	0	0	9	4.91	2.15
8 < 9										10	5.13	2.27
9 < 10										3	4.89	1.82
10 < 11										0	3.32	1.50
11 < 12										0	1.63	1.42
12 < 13										0	.25	.54

Table B.7 Expected and Actual Number of Days During the Boro Season on Which the Given Total Number of Tractor Days of Tillage were Demanded in the Comilla Thana

Demand Tractor-Days	Number of days on which given demand occurs											
	1966			1967			1968			1969		
	Actual	Predict	Std dev	Actual	Predict	Std dev	Actual	Predict	Std dev	Actual	Predict	Std dev
< 2	26	46.41	5.47	29	26.91	4.08	20	21.57	4.23	13	16.51	3.30
2 < 3	17	10.35	3.37	11	15.55	3.76	8	15.99	3.95	12	13.09	4.12
3 < 4	4	1.19	1.22	12	9.83	3.19	6	16.22	3.46	3	13.16	3.20
4 < 5	3	.03	.17	10	4.55	2.32	12	14.34	4.26	6	11.68	3.17
5 < 6				6	1.24	1.35	12	10.20	3.06	8	9.59	3.26
6 < 7				2	.07	.29	4	5.40	2.19	6	5.95	2.73
7 < 8							12	2.54	1.78	9	4.64	2.39
8 < 9							1	.93	1.11	13	5.08	2.27
9 < 10							0	.17	.45	9	5.43	2.31
10 < 11							0	.01	.10	3	4.11	1.77
11 < 12										1	3.27	1.73
12 < 13										0	1.52	1.35
13 < 14										0	1.00	1.19
14 < 15										0	.30	.58
15 < 16										0	.06	.24

Table B.8 Expected and Actual Number of Days During Aus Season on Which the Given Number of Tractor Days of Tillage were Demanded in the Comilla Thana

Demand Tractor-Days	Number of days on which given demand occurs											
	1966			1967			1968			1969		
	Act-ual	Pre-dict	Std dev	Act-ual	Pre-dict	Std dev	Act-ual	Pre-dict	Std dev	Act-ual	Pre-dict	Std dev
< 2	13	12.13	2.66	14	9.12	2.16	6	8.45	2.18	11	10.16	2.68
2 < 3	6	4.61	2.24	6	4.03	1.88	4	5.24	2.22	5	5.93	2.39
3 < 4	3	4.08	1.98	9	3.08	1.92	2	4.03	2.24	2	3.67	2.12
4 < 5	2	4.69	2.03	4	2.55	1.60	0	2.65	1.60	0	2.55	1.70
5 < 6	0	2.89	1.44	3	2.68	1.56	3	2.08	1.61	3	2.14	1.58
6 < 7	4	1.20	1.28	1	2.85	1.70	1	1.77	1.42	6	2.24	1.54
7 < 8	0	.07	.29	0	2.34	1.25	1	1.90	1.43	3	2.35	1.89
8 < 9				0	2.27	1.39	4	1.83	1.11	2	2.25	1.43
9 < 10				0	1.86	1.30	0	1.95	1.36	1	2.06	1.32
10 < 11				0	.72	.82	4	1.71	1.35	2	1.50	1.24
11 < 12				0	.32	.55	2	1.48	1.28	1	1.25	1.12
12 < 13				0	.01	.10	3	1.65	1.23	0	.65	.91
13 < 14							0	1.19	1.09	0	.23	.51
14 < 15							2	.91	1.06	0	.03	.17
15 < 16							1	.73	.92			
16 < 17							0	.24	.49			
17 < 18							0	.11	.42			

Table B.9 Expected and Actual Number of Days During the Amon 1 Season on Which the Given Number of Tractor Days of Tillage were Demanded in the Comilla Thana

Demand Tractor-Days	Number of days on which given demand occurs											
	1966			1967			1968			1969		
	Actual	Predict	Std dev	Actual	Predict	Std dev	Actual	Predict	Std dev	Actual	Predict	Std dev
< 2	17	33.54	4.89	33	42.88	5.12	15	26.37	3.99	40	17.52	2.78
2 < 3	7	.44	.80	12	10.81	3.36	6	15.85	3.86	12	12.68	3.54
3 < 4				1	1.05	1.19	7	9.82	2.95	7	11.57	3.33
4 < 5							6	4.57	2.33	4	7.64	2.58
5 < 6							4	.99	1.15	1	5.82	2.46
6 < 7							1	.04	.32	1	2.87	1.73
7 < 8										0	1.05	1.17
8 < 9										0	.04	.20

Table B.10 Expected and Actual Number of Days During Amon 2 Season on Which the Given Number of Tractor Days of Tillage were Demanded in the Comilla Thana

Demand Tractor-Days	Number of days on which given demand occurs											
	1966			1967			1968			1969		
	Actual	Predict	Std dev	Actual	Predict	Std dev	Actual	Predict	Std dev	Actual	Predict	Std dev
< 2	27	35.70	3.92	32	32.44	4.32	24	27.82	4.06	26	27.29	3.87
2 < 3	6	6.18	2.56	14	11.53	3.29	3	11.93	3.38	12	12.75	3.65
3 < 4	6	.01	.10	5	5.28	2.61	6	7.93	2.35	7	9.22	2.94
4 < 5	2	0	0	3	.39	.76	3	3.69	2.13	13	6.54	2.32
5 < 6							4	.48	.90	5	3.27	1.65
6 < 7							2	0	0	0	.67	.93

Table B.11 Normal Operation Values of Variables Used in Determining Tractor and Implement Operating Capacity

IDENT	DESCRIPTION	HARROW	ROTARY
CAP	Tillage tool capacity, acres/day	--	--
EFFIMWD	Effective implement width, ft.	--	--
FUEL	Fuel Consumption, Gal/acre	1.25	1.55
FUELCT	Fuel cost, currency/day	--	--
FUELPRC	Fuel price, $/gal Rs/gal	.57 2.70	.57 2.70
PLOTSIZ	Plot size, acres	.30	.30
TILTIM	Theoretical field time, hrs/plot		
TILOVLP	Tillage implement overlap, dec. %	.10	.10
TILSPD	Tillage speed, mph	3.5	2.5
TIMIDLE	Idle time, hrs/day	5.0	5.0
TURNNUM	Number of passes, also turns	--	--
TURNRAD	Turning radius, ft.		
TURNSPD	Turning speed, mph.	2.0	2.0
TURNTIM	Turning time, hrs/plot	--	--
WIDTHFD	Width of the field, ft	--	--
WIDTHIM	Implement width, ft	6.5	6.5
WIDTHTR	Tractor width, ft	6.5	6.5
WORKHRS	Working hours, hr/day	10	10

Table B.12 **Normal Operating Values of Variables Used in Determining Tractor and Implement Costs**

IDENT	DESCRIPTION	VALUE
ALOWFLD	Drivers field allowance	Rs. 1.5
ALOWHS	Housing allowance, proportion of monthly salary per year	1.2
ALOWMD	Medical allowance, proportion of monthly salary per year	1.0
COMM	Coop manager commission/day	Rs. 5.0
DDLY	Import and delivery delay, seasons	
	Tractor :	2
	Harrow :	2
	Rotovator :	2
INSUR	Insurance rate	2%
INT	Interest rate	7.5%
INTPRC	Initial price	
	Tractor:	Rs. 13,500
	Harrow:	Rs. 1700
	Rotovator:	Rs. 3600
LIFE	Life in days of operation	
	Tractor:	1200
	Harrow:	1000
	Rotovator:	800
MCIFL	Machinery inflation	5%
SALMGR	Managers salary/yr	Rs. 3600
SALMO	Basic salary	Rs. 120
SALSUP	Superintendents salary/yr	Rs. 2400
SALVAL	Salvage value	
	Tractor:	Rs. 1200
	Harrow:	0
	Rotovator:	0
STO	Tractor housing cost	Rs. 500
TRDRV	Drivers per tractor	2
TRMCH	Mechanics per tractor	.25
WAGEIFL	Wage inflation/yr	10%
YRINC	Yearly salary increase/mo	Rs. 10

APPENDIX C

Table C.1 Partial Regression Coefficients for Predicting the Occurrence of a Tractor Breakdown

Identi-fication	Description	Value
b_1	Partial regression coefficient, constant	4.932674×10^{-3}
b_2	Partial regression coefficient for t	1.0325726×10^{-4}
b_3	Partial regression coefficient for t^2	-2.931516×10^{-7}
b_4	Partial regression coefficient for t^3	$2.5337558 \times 10^{-10}$
b_5	Partial regression coefficient for t^4	$-4.6761736 \times 10^{-14}$

Table C.2 Value for the Parameters of the Exponential Equation for Fitting Accumulated Percent of Repair to Repair Duration

Tractor Work Period, days	a	b	Correlation Coefficient
MF 35			
0 - 200	2.05	4.48	.95
201 - 400	3.41	2.37	.99
401 - 600	1.96	5.18	.98
601 - 800	3.75	4.34	.99
801 - 1000	3.73	4.53	.98
1001 - 1200	3.80	3.87	.97
MF 135			
0 - 200	2.73	4.23	.97
201 - 400	4.09	3.51	.97

Table C.3 Values of the Parameters Used by the Model to Predict Repair Durations

Identification	Description	Value
a_1	Multiplication parameter for equation 5.3.2 when accumulated tractor use is less than 600 days	2.051141559
b_1	Exponential parameter for equation 5.3.2 when accumulated tractor use is less than 600 days	4.4831864
a_2	Multiplication parameter for equation 5.3.2 when accumulated tractor use is more than 600 days	3.75343671
b_2	Exponential parameter for equation 5.3.2 when accumulated tractor use is more than 600 days	4.340511

Table C.4 Parameters of the Repair Model of the Tractor Hire Service Simulation

Identi-fication	Description	Value
a_1	Constant regression coefficient in equation 5.4.1	-101.03125606
a_2	Regression coefficient multiplied times duration in equation 5.4.1	144.82128493
b	Power to which duration is raised in equation 5.4.1	.5

Table C.5 Actual Cost/Estimated Total Cost as a Function of the Percent of Total Repair for a Given Duration Range

Repair Duration Ranges, days	Ratio of Actual to Estimated Cost									
	Proportion of Repairs									
	.10	.20	.30	.40	.50	.60	.70	.80	.90	1.00
1 - 2	.11	.21	.24	.43	.57	.81	1.14	2.13	2.86	5.39
3 - 5	.06	.13	.22	.34	.45	.62	.62	1.32	2.13	5.37
6 - 10	.06	.18	.37	.42	.56	.62	.73	1.03	1.32	4.14
11 - 20	.05	.11	.16	.25	.34	.46	.57	.84	1.69	5.36
21 - 50	.01	.11	.46	.59	.76	1.11	1.47	2.17	3.03	5.02
51 - 100	.04	.04	.14	.17	.19	.29	.48	.54	1.24	2.15
over 100	.21	.52	.79	1.01	1.33	1.53	1.80	1.85	2.05	2.91

Table C.6 Repair Model Parameter Values for Equation 5.4.5 of Chapter 5

Duration Ranges, days	c_1	c_2
< 2	.0849	3.687
3 - 5	.0931	3.073
6 - 10	.1505	2.481
11 - 20	.0721	3.211
21 - 50	.1308	3.131
51 - 100	.0250	4.259
> 100	.0352	2.390

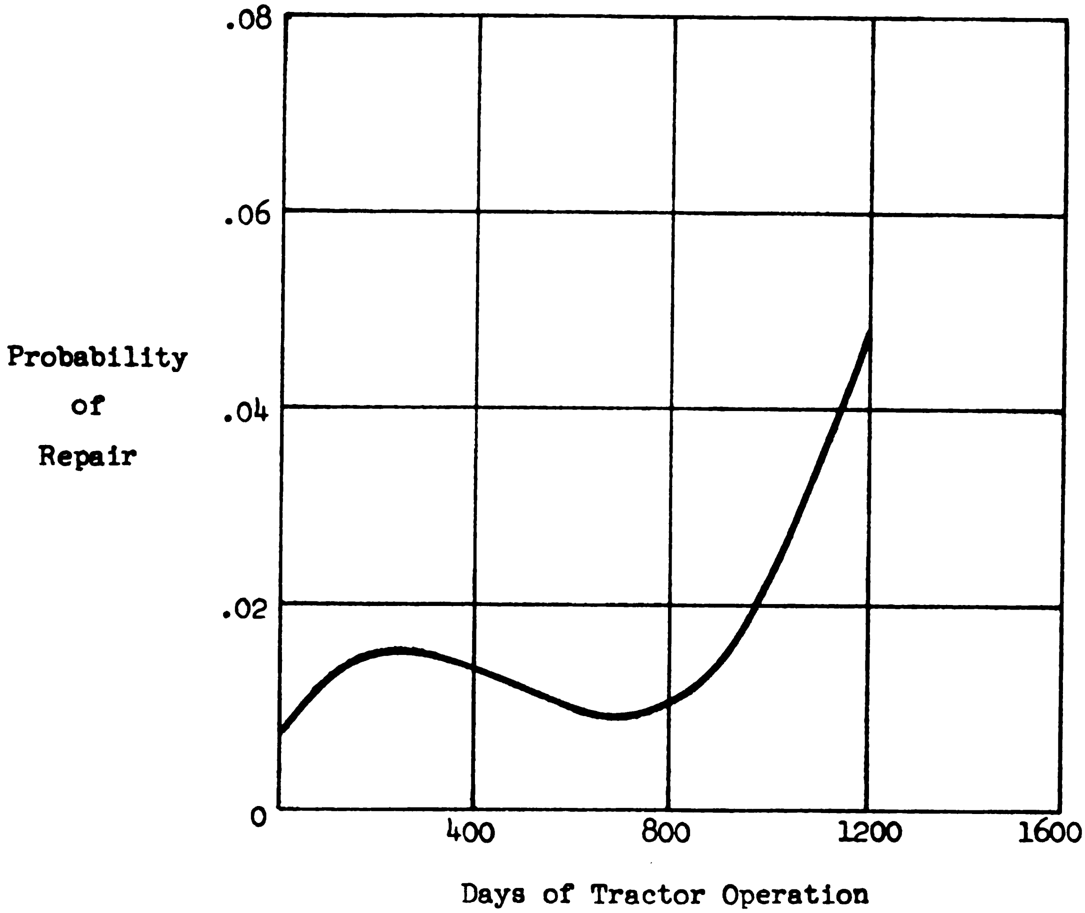

Figure C.1 Probability of Repair as a Function of Days of Tractor Operation, Best Fit of Least Squares 4th Order Polynomial

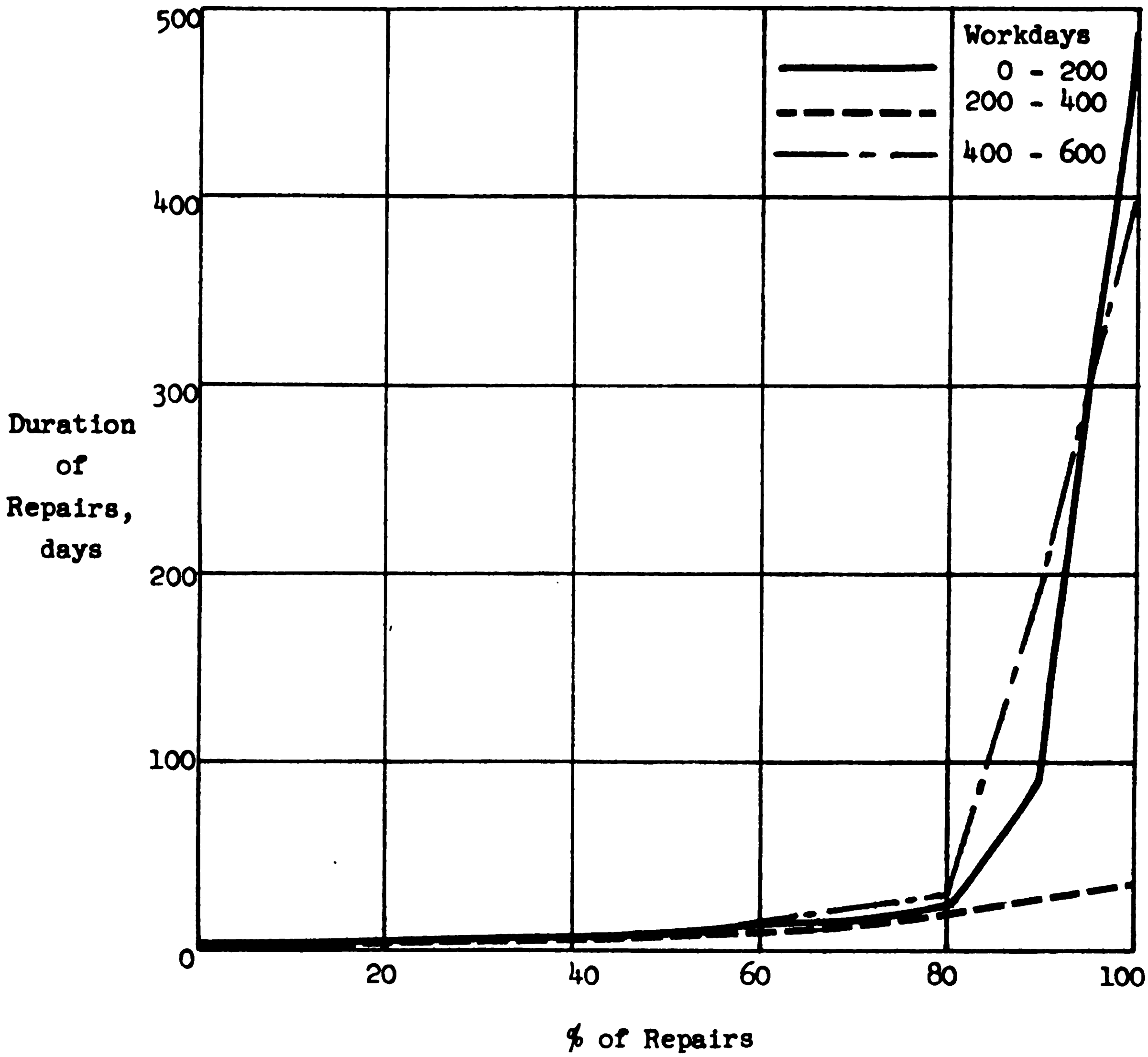

Figure C.2 Duration of Repair as a Function of the Accumulated Percent of Repairs in 200 Work-day Intervals for MF 35 Tractors

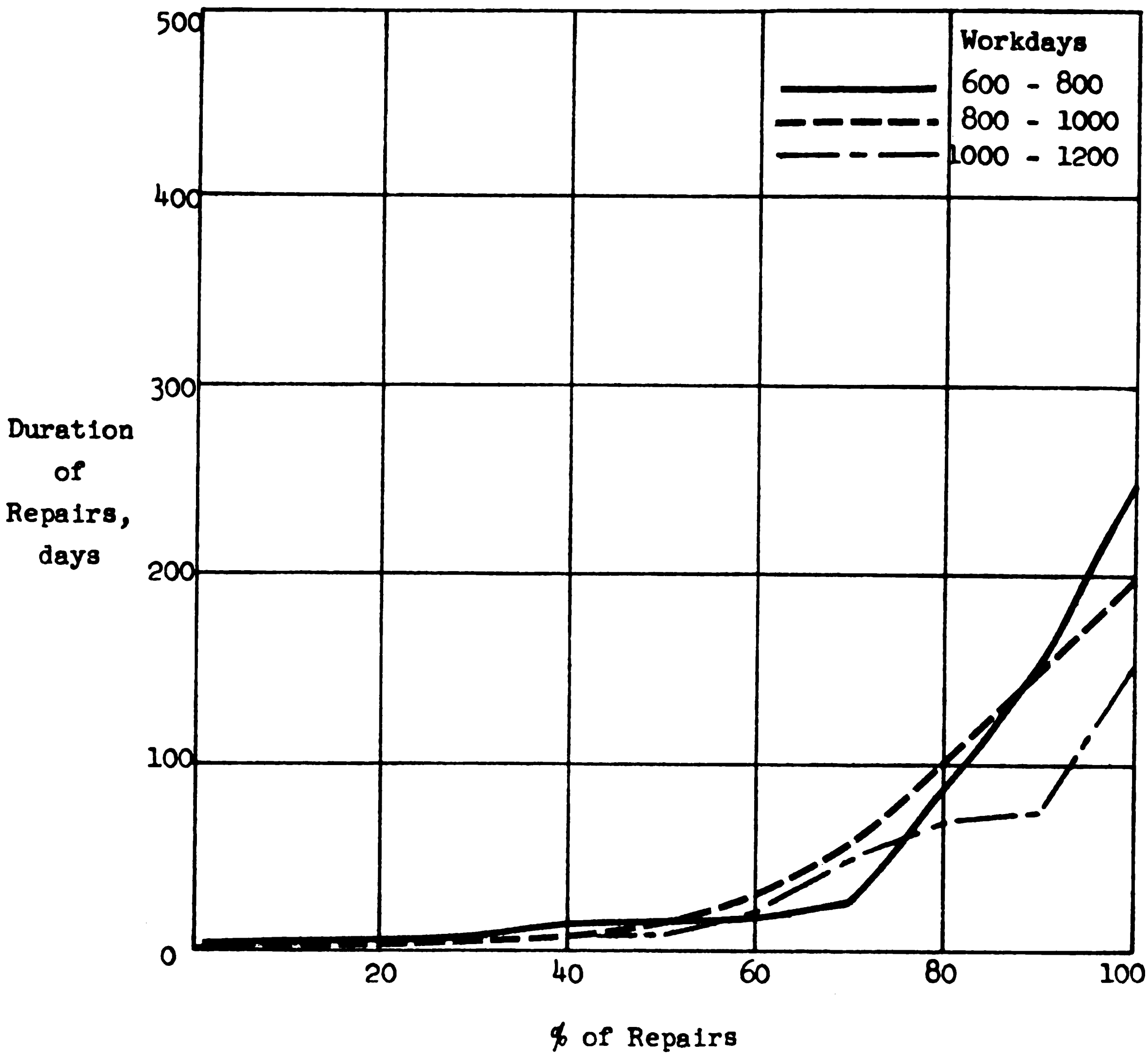

Figure C.3 Duration of Repair as a Function of the Accumulated Percent of Repairs in 200 Work-day Intervals for MF 35 Tractors

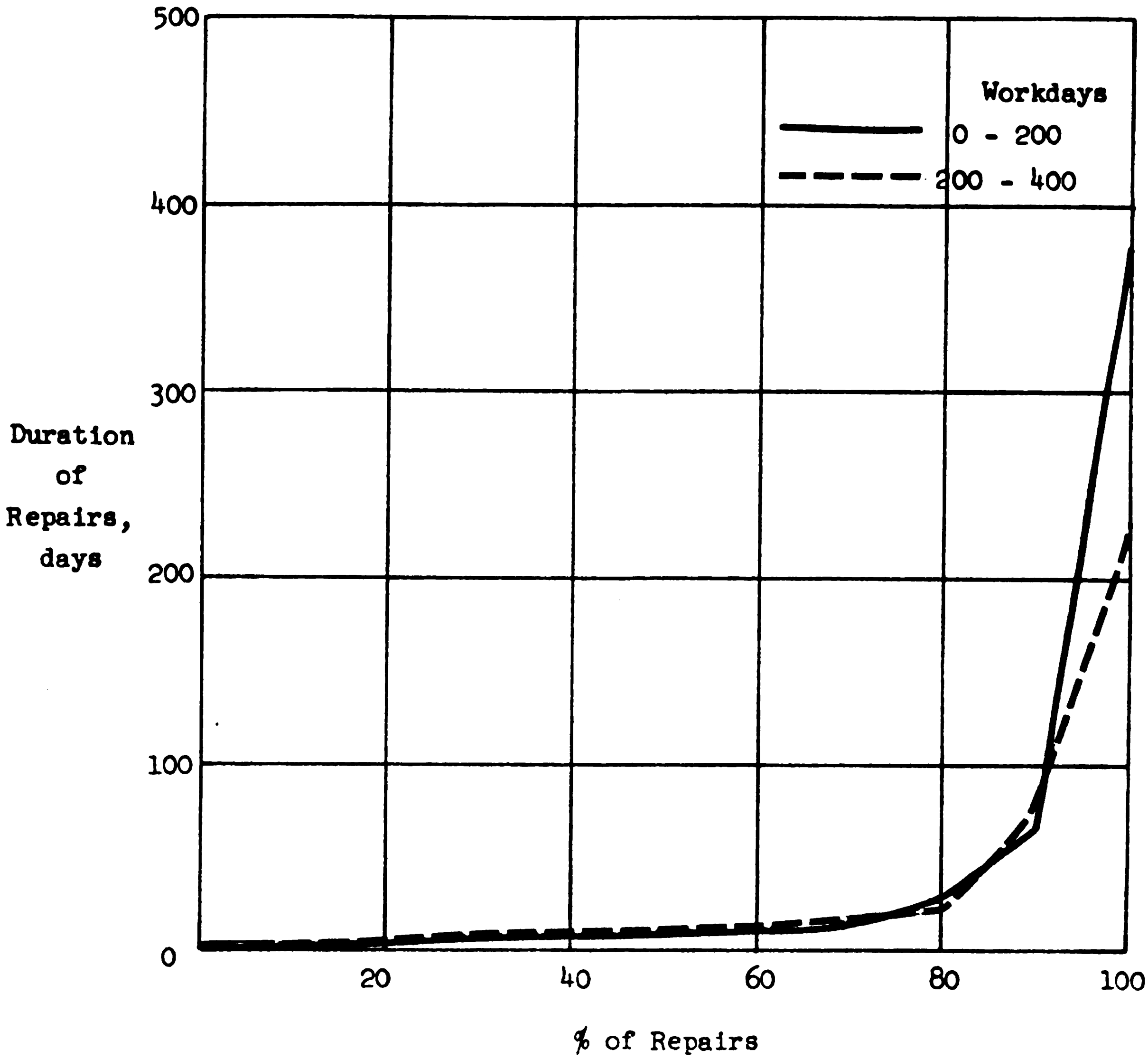

Figure C.4 Duration of Repair as a Function of the Accumulated Percent of Repairs in 200 Work-day Intervals for MF 135 Tractors

APPENDIX D

APPENDIX D

PROPOSAL FOR DOCTORATE RESEARCH

SUBMITTED TO: Midwest Universities Consortium for International Activities in Spring 1969

TITLE: Computer Simulation of a Cooperative Approach to Tractor Mechanization in a Developing Country

LOCATION: Comilla, East Pakistan and other cooperative tractor stations in East Pakistan

LEADERS: Dr. Merle L. Esmay and Mr. LeVern W. Faidley

COOPERATORS: Department of Agricultural Engineering, and the Institute for International Agriculture, Michigan State University; Pakistan Academy for Rural Development and Kotwali Thana Central Cooperative Association, Comilla, East Pakistan

JUSTIFICATION:

East Pakistan, located in the northeast corner of the Indian subcontinent, is comprised of 55,000 square miles of land and has an estimated population of 67.5 million people. It thus is one of the most densely populated countries in the world. About 85% of its population is engaged in agriculture. The average land holding of a farmer is 3.5 acres which is divided into 6.6 pieces that are often widely separated.

Because of the large population, there are problems with producing enough food. Even with the large number of people in agriculture, during the periods of land preparation and harvesting, there is insufficient labor available. Bullocks have been the major source of power for centuries. They have been in competition with man for food for the last several decades, thus are small and emanciated and no longer strong enough to work all of the land that is available for crop production. Also, with the introduction of new and improved varieties of crops, the need for better and more timely preparation of land has become critical.

To meet this power need the introduction of tractors is desirable. However, the land holdings of individual farmers and the income from this land is so small that individual ownership of mechanical sources of power is impossible.

One feasible solution to this problem is the cooperative ownership of tractors and equipment. Here, a cooperative association would own the tractor, train drivers to operate them and mechanics to service them. These tractors with drivers would then be available for hire by village cooperatives. An example of this type of operation is the Comilla Cooperative Tractor Station in Comilla, East Pakistan.

Experimental tractor stations have not broken even in their operation. This loss may not be entirely undesirable, because of the service that is being performed. However, if cooperative tractor stations are to be operated in many areas, the loss must be minimized and guidelines for efficient operation need to be developed.

The objective of this project is to identify the problems and to formulate guidelines for better and more efficient operation of the cooperative approach to mechanization.

This will be accomplished in two phases. First, the records of the existing tractor stations will be tabulated. Second, these records will be analyzed and guidelines for future operations will be formulated. To help in this formulation it is proposed that a computer simulation model of the tractor station be developed. The model will be used to test the effect of making certain changes in the tractor stations operation and should prove very useful in optimizing the operation and in formulating the guidelines.

OBJECTIVES:

1. To establish guidelines for the efficient operation of cooperative tractor hire stations.

2. To establish the criteria for expansion of the cooperative-type mechanization systems into other areas.

3. To develop a computer simulation model of the tractor hire station which will accurately model its operation and which can be used as a tool to optimize tractor station operation.

RATIONALE:

1. The research will supplement a larger study of mechanization in Pakistan being proposed by Dr. M. L. Esmay, professor of Agricultural Engineering, Michigan State University.

2. The applicant, supported by Michigan State University, has been to Comilla, East Pakistan and collected preliminary data concerning mechanization and irrigation related to the proposed project.

3. Quite good records of tractor station operations are available at Comilla, East Pakistan.

4. Data concerning the operation and maintenance of the tractors have been collected and tabulated.

5. Cooperation of the people at Comilla and the feasibility of obtaining information in Pakistan has been established.

6. The computer simulation model will have additional applications in analyzing tractor hire pools and government tractor stations in many other countries.

7. The location of the information needed and procedures for obtaining this information have been determined.

TRACTOR STATION OPERATION AND SIMULATION:

Figure A.1 is a schematic of the physical operation of a cooperative tractor station. The request for tractors and the type of work to be done is originated in the village cooperatives.

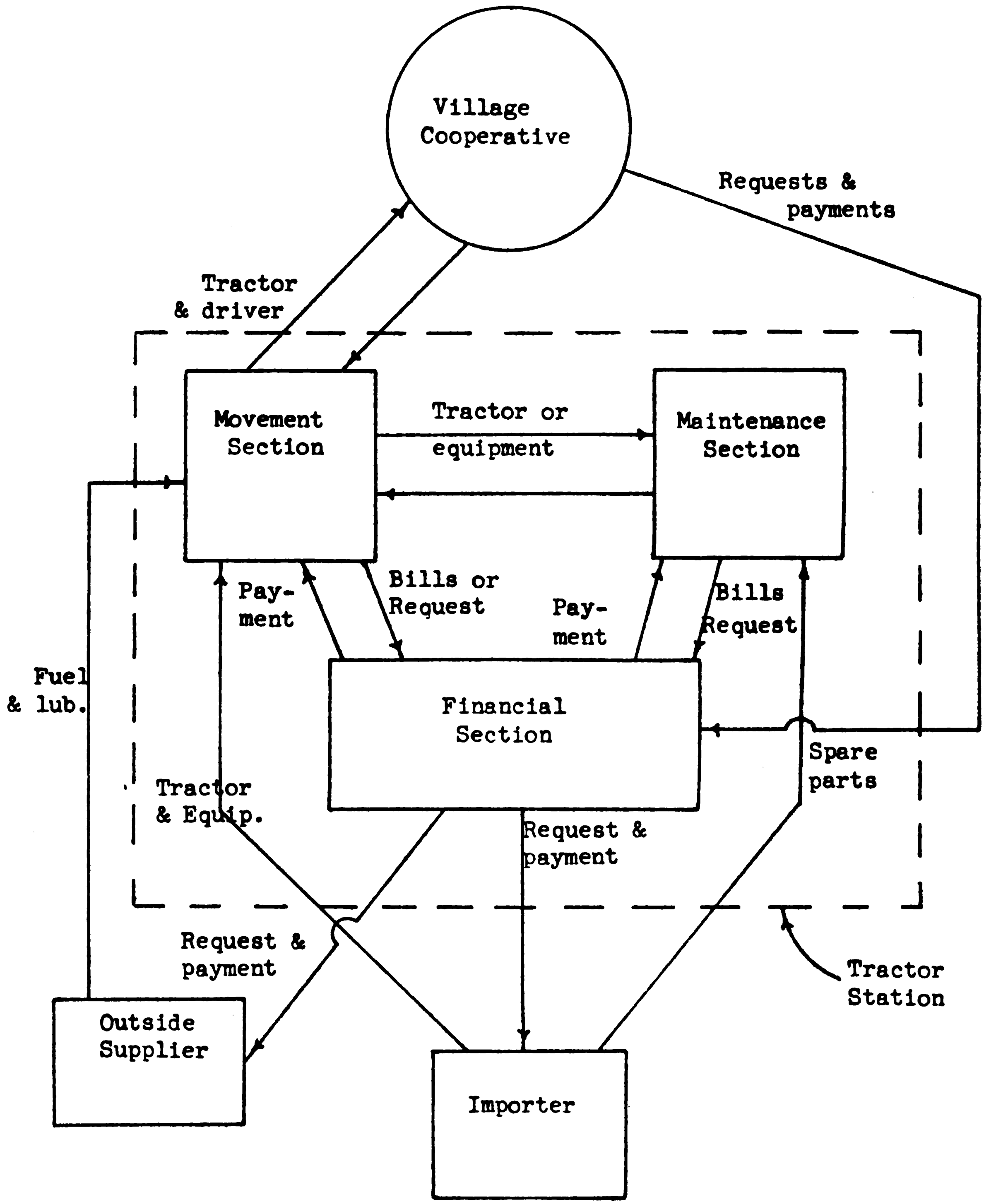

Figure D.1 Flow Diagram of Tractor Station Operation

The information needed to be able to analyze the village cooperatives is:

1. Type and number of requests in relation to location, number of members, financial status, and age of the village cooperative.

2. Effect of tube wells on requests.

3. Distribution of the number and types of requests as a function of time during the year. (already tabulated)

4. Delays involved in submitting and carrying out the requests.

The tractor station is made up of three main sections: movement, maintenance and financial. The movement section is where the tractors and equipment are stored. The tractors are dispatched from here when requests are received. The maintenance section is where repair of the tractors and equipment is done and where repair parts are stored. The financial section is where requests and payments for hiring the tractors are received. Payments of bills are made from this section.

The information needed from each section is:

<u>Movement section</u>

1. Number of tractors available for the different types of work as a function of time throughout the year. (already tabulated)

2. Cost and quantities of fuel and lubricants required for the type of work done. (already tabulated)

3. Delay between receiving a request and carrying out the work as a function of time.

4. Cost and personnel required to operate the section.

5. Cost and depreciation of the buildings and equipment of the section.

6. Delay between noticing a need for repair and the time the machine is taken to the maintenance section for repair.

Maintenance section

1. Inventory of and investment in tools, equipment and spare parts.
2. Cost and number of personnel required for operation of the section.
3. Delay between receiving a piece of equipment and when actual repair is started.
4. Time required for different types of repair. (partially tabulated)
5. Delay when parts are not available at the maintenance section and must be imported.
6. Breakdown of total costs into cost of maintenance and labor. (partially tabulated)

Financial section

1. Prices charged for the different types of work done.
2. Procedures for buying new equipment and selling of the old.
3. Total income from each type of work as a function of time.

Information needed concerning the outside supplier:

1. Prices for the fuels and lubricants. (already tabulated)
2. Delay between request and delivery of the orders.

Information needed to analyze the imports includes:

1. Delays between receiving a request and sending out the order for the equipment.
2. Delays between sending the order and receiving the equipment at the port.
3. Delays between receiving the equipment by the importer and its delivery to the tractor station.
4. Restrictions and procedures for importing agricultural machinery.

This concludes the listing of the information which seems necessary to explain the operation of the tractor station at the present time. Other information can be added if it appears necessary in the formulation of the guidelines.

PROCEDURES:

Information will be gathered from three sources in Comilla, East Pakistan: 1) the records of past operation stated in the documentation section of the Pakistan Academy of Rural Development Library, 2) the financial records kept at Kotwali Thana Central Cooperative Association headquarters at Abboy Asram, and 3) the current record maintained at the tractor station. In addition, information will be gathered from other cooperative tractor stations in East Pakistan.

Data analysis will be done at Michigan State University with the use of the CDC 6500 computer.

TIME TABLE: August 1969 - August 1970: Data collection in East Pakistan
August 1970 - June 1971: Analysis at Michigan State University

BIBLIOGRAPHY

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Abercrombie, K. C., "Rural employment - a primary objective", CERES #31, FAO Review on Development, Food and Agriculture Organization: Rome, Italy, 1973.

Akhter, Farkunda, "Characteristics of the Members of Comilla Cooperatives", Survey and Research Bulletin, No. 10, Pakistan Academy for Rural Development: Comilla, East Pakistan, 1964.

Agricultural Engineers Yearbook, American Society of Agricultural Engineers: St. Joseph, Michigan, 1972.

Cervinka, Vaclav, "Tractor and Implement Efficiency on Tropical Farms", Agricultural Engineering Department, California State Polytechnic College: San Luis Obispo, California, 1969.

Chancellor, W. J., "Survey of Tractor Contractor Operations in Thailand and Malaysia", Agricultural Engineering Department, University of California: Davis, California, 1970.

Cost and Returns (data forms), Pakistan Academy for Rural Development: Comilla, East Pakistan, 1965-1969. (unpublished)

Donaldson, Graham F., "Operational Problems in the Introduction of Power Tillers to Farms in East Pakistan", International Bank for Reconstruction and Development: Washington, D.C., 1970.

Donaldson, Graham F. and McInerney, John P., "The Consequences of Farm Tractors in Pakistan", Development Economics Department, International Bank for Reconstruction and Development: Washington, D.C., March 1973.

Esmay, M. L. and Faidley, L. W., "Agricultural Mechanization and Labor Utilization in Asia", American Society of Agricultural Engineers, St. Joseph, Michigan, Paper No. 72-530, June, 1972.

Fridley, R. B. and Holtman, J. B., "Predicting the Socio-Economic Implications of Mechanization by Systems Analysis", American Society of Agricultural Engineers: St. Joseph, Michigan, Paper No. 73-5501, December, 1973.

Giles, G. W., "Toward A More Powerful Agriculture", Report to the Government of West Pakistan, Agriculture Department, Government of West Pakistan: Lahore, Pakistan, November 1967

Gotsch, Carl H., "Tractor Mechanization and Rural Development in Pakistan", International Labour Review, vol. 107, no.2, February 1973.

Hoque, Anwarul, "Cost and Returns from Winter Crops", Pakistan Academy for Rural Development: Comilla, East Pakistan, 1970. (unpublished)

Hunt, D. R. and Bowers, W., "Application of Mathematical Formula to Repair Cost Data", Transactions of the American Society of Agricultural Engineers: St. Joseph, Michigan, 1970, vol. 13, no. 6.

Hunt, Donnell, Farm Power and Machinery Management, 4th ed., Iowa State University Press: Ames, Iowa, 1964.

Johl, S. S., "Farm Size, Economic Efficiency and Social Justice (A Case of Punjab)", Agricultural Mechanization in Asia, Farm Machinery Industrial Research Corp.: Tokyo, Japan, Spring 1973.

Kane, Edward J., Economic Statistics and Econometrics, Harper and Row: New York, New York, 1968.

Lee, H. T., "Agricultural Diversification and Development", SEADAG Papers, The Asia Society: 505 Park Avenue, New York, New York, 1971.

Manetsch, T. J. and Park, G. L., "Systems Analysis and Simulation with Applications to Economic and Social Systems", Department of Electrical Engineering and System Science, Michigan State University: East Lansing, Michigan, September 1972.

Mohsen, A. K. M., "Evaluation of the Thana Irrigation Programme in East Pakistan (1968-1969)", Pakistan Academy for Rural Development: Comilla, East Pakistan, 1969.

Mukumoto, Tsutomu, "Changes and Mechanization in Agriculture in Japan", Farm Machinery Industrial Research Corp.: Tokyo, Japan, FRIR 9 (27), 1969.

Muyeed, Abdul, "Strategies Involved in a Development System of Planned Social Change in Rural East Pakistan", Ph.D. Thesis, Michigan State University: East Lansing, Michigan, 1969.

"A New Rural Co-operative System for Comilla Thana -- Rural Co-operative Pilot Experiment", Sixth Annual Report, Pakistan Academy for Rural Development: Comilla, East Pakistan, 1967.

"Pakistan Academy for Rural Development Eighth Annual Report", Pakistan Academy for Rural Development: Comilla, East Pakistan, 1967.

"Pakistan Academy for Rural Development Tenth Annual Report", Pakistan Academy for Rural Development: Comilla, East Pakistan, 1969.

Raper, A. F., Rural Development in Action, Cornell University Press: Ithaca, New York, 1970.

Rau, J. G., Optimization and Probability in Systems Engineering, Van Nostrand Reinhold Company: New York, 1970.

Research and Survey Bulletin No. 1, "Livestock Population in the Comilla Thana", Pakistan Academy for Rural Development: Comilla, East Pakistan, January 1964.

Shaw, Robert d'A, "Jobs and Agricultural Development", Overseas Development Council: New York, New York, Monograph Number 3, 1970.

Stout, B. A., "The Use and Future of Heavy Tractors and Implements in West Africa", Presented at a Seminar on the Mechanization of Agriculture in West Africa at Bombay, Senegal, 1971.

Stout, B. A. and Downing, C. M., "Selective Employment of Labour and Machines for Agriculture Production", Department of Agricultural Engineering, Michigan State University: East Lansing,Mich., 1973.

United Nations, "World Population Prospects as Assessed in 1963", Population Studies, No. 41, 1966.

"Winter Crop Cutting Survey, Comilla Kotwali Thana", Pakistan Academy for Rural Development: Comilla, East Pakistan, 1965, 1966, 1967, 1968, 1969.

Winter Crop Cutting Surveys, Comilla Kotwali Thana (data forms), Pakistan Academy for Rural Development: Comilla, East Pakistan, 1966, 1967, 1969, 1970. (unpublished)